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FOREWORD

The *Proceedings* of the American Society for Testing Materials are published annually and include all reports and papers offered to the Society during the current year and accepted by the Administrative Committee on Papers and Publications for the *Proceedings*, together with discussion.

The table of contents and subject and author indexes cover all papers and reports published by the Society during the current year, which in addition to those appearing in the *Proceedings* include those accepted for publication in the ASTM BULLETIN or in Special Technical Publications.

A list of the Special Technical Publications published by the Society in 1954 is given on page 1388 of this volume. This supplements the lists appearing in the *Proceedings* from 1948 to 1953 covering all special publications published by the Society up to and including 1953.

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Correlation of Gamma Radiography and Magnaflux Indications in the Inspection of Large Cast-Steel Connecting Rods—R. L. Thompson (*see* ASTM BULLETIN *No. 197, April 1954, p. 58* (*TP 86*))
Radiographic-Performance Correlation in Ordnance Design and Evaluation—D. T. O'Connor and E. L. Criscuolo (*published in Special Reprint only*)
Flash X-ray Studies of Fuze Performance—E. L. Criscuolo and D. T. O'Connor (*published in Special Reprint only*)
The Reliability of Fluoroscopic Inspection of Extruded Propellant—D. Polansky and D. T. O'Connor (*published in Special Reprint only*)
Radiographic-Micrographic Examination of Aluminum Resistance Weld—N. Modine and D. T. O'Connor (*published in Special Reprint only*)

SUMMARY OF PROCEEDINGS OF WASHINGTON NATIONAL MEETING

Symposium on Color of Transparent and Translucent Products

Summary of Proceedings on Color of Transparent and Translucent Products 1387

Symposium on Design of Experiments

Summary of Proceedings of the Symposium on Design of Experiments 1387

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Insert Plates
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SUMMARY OF PROCEEDINGS
OF THE
FIFTY-SEVENTH ANNUAL MEETING

Chicago, Ill., June 13–18, 1954

This summary of the Fifty-seventh Annual Meeting of the American Society for Testing Materials, held at the Hotels Sherman and Morrison, Chicago, Ill., June 13–18, 1954, is a record of the transactions of the meeting, including the actions taken on the various recommendations submitted by the technical committees. In all, 36 technical sessions were held.

The registered attendance of the meeting is as follows: Members present or represented, 1223; committee members, 700; guests, 306; total, 2229; ladies, 178.

The Proceedings are set forth session by session. There were 72 reports and 100 formal papers presented. The record with respect to each has been briefed, the recommendations in the reports have been grouped so as to cover the acceptance of material for publication as tentative, such as new specifications, methods of test, revisions of tentatives, and proposed revisions of existing standards, and, as a separate group, the approval of matters that were referred to letter ballot of the Society, comprising the adoption of tentatives as standard and the adoption of revisions of standards. Accordingly, wherever the action is reported “adopted as standard” or “adopted as standard, revisions in,” it is understood that this indicates approval of the Annual Meeting for reference to letter ballot of the Society.[1] The various recommendations so recorded are included in the Society letter ballot. The actions designated as “accepted as tentative” or “accepted as tentative, revisions in” are self-evident as indicating acceptance by the Society at the Annual Meeting for publication as tentative. Designations that have since been assigned to new tentatives are included as information.

While all the items on the program are recorded under the particular session in which they are presented, for convenience in locating actions with respect to any particular report, the accompanying list is presented of all reports together with the page reference where the actions thereon are recorded:

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[1] The letter ballot on recommendations affecting standards, distributed to the Society membership, will be canvassed on September 15, 1954.

LOCATION OF ACTIONS ON COMMITTEE REPORTS

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A-3 on Cast Iron 28
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C-22 on Porcelain Enamel 15

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D-2 on Petroleum Products and Lubricants 29
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D-4 on Road and Paving Materials 11
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Symposium on Temperature Stability of Electrical Insulating Materials 4, 7
Symposium on Odor 10, 13
Symposium on Permeability of Soils 10, 13
Symposium on Effect of Cyclic Heating and Stressing on Metals at Elevated Temperatures 22
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Papers on Testing 3
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Papers on Significance of Tests of Concrete 16
Papers on Creep 25
Papers on Concrete, Cementitious Materials 25
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FIRST SESSION—OPENING SESSION

MONDAY, JUNE 14, 10:00 A.M.

FORMAL OPENING OF THE FIFTY-SEVENTH ANNUAL MEETING, PRESIDENT L. C. BEARD, JR.

The session was first formally opened by President L. C. Beard, Jr., who called attention to the very complete program of events that were to follow during the ensuing week. The meeting was then turned over to the session chairman, John E. Ott, Chairman of the Chicago District Council and Vice-Chairman of the Chicago Committee on Arrangements.

TESTING

SESSION CHAIRMAN: J. E. OTT

An Inexpensive Constant-Load Testing Machine—M. E. Clark and O. M. Sidebottom, presented by Mr. Clark.[2]

Size Effect in the Tension Test of Mild Steel—Cedric W. Richards, presented by the author.

Production Testing of Bonded Materials with Ultrasonics—A Survey of Theory and Application—G. B. Baumeister. (Presented by title.)[3]

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[2] Published in the ASTM BULLETIN, No. 203, January, 1955, p. 69 (TP 29).

[3] Published in the ASTM BULLETIN, No. 204, February, 1955, p. 50 (TP 52).

A New Triaxial Stress Testing Machine for Determining Plastic Stress-Strain Relations—H. A. B. Wiseman and Joseph Marin, presented by Mr. Wiseman.

Committee E-4 on Metallography:

Report presented by title.

Appended Paper:

Electron Microstructure of Tempered Bainite and Tempered Martensite in Steel—W. L. Grube, presented by title.

SECOND SESSION—SYMPOSIUM ON COAL SAMPLING[4]

MONDAY, JUNE 14, 2:00 P.M.

SESSION CHAIRMAN: H. F. HEBLEY

CO-CHAIRMAN: W. W. ANDERSON

Introduction—H. F. Hebley.

The Development of the Theoretical Basis of Coal Sampling—W. M. Bertholf, presented from manuscript by the author.

Some Recent British Work on Coal Sampling—R. C. Tomlinson, presented from manuscript by the author.

Tests on the Binomial Sampling Theory—Jan Visman, presented from manuscript by the author.

(*Symposium Continued in Fifth Session*)

THIRD SESSION—SYMPOSIUM ON TEMPERATURE STABILITY OF ELECTRICAL INSULATING MATERIALS[5]

MONDAY, JUNE 14, 2:00 P.M.

SESSION CHAIRMAN: L. B. SCHOFIELD

CO-CHAIRMAN: K. N. MATHES

Measurements of Dielectric Properties at Temperatures Up to 500 C—A. H. Scott, P. Ehrlich, and J. F. Richardson, presented from manuscript by Mr. Scott.

Dielectric Measurements on Plastics at High Temperatures—Thomas Hazen, presented by the author.

Electrical Resistivity of Bonded Micaceous Materials at Elevated Temperature—K. Wechsler, presented by the author.

Test Methods for Studying Thermal Stability and Heat Aging of Insulating Varnish—A. H. Haroldson, presented by the author.

Thermal Stability of Insulating Fabrics—R. C. Bartlett, presented by the author.

(*Symposium Continued in Sixth Session*)

FOURTH SESSION—REPORT SESSION

MONDAY, JUNE 14, 4:30 P.M.

SESSION CHAIRMAN: J. H. FOOTE

Committee A-6 on Magnetic Properties:

Report presented by R. L. Sanford, chairman, and the following actions taken:

Accepted as Tentative:

Spec. for Flat-Rolled Grain-Oriented Electrical Steel, 3 per cent Silicon Content, in Cut Lengths or Coils (A 378 - 54 T)

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[4] Issued as separate technical publication *ASTM STP No. 162.*

[5] Issued as separate technical publication *ASTM STP No. 161.*

Spec. for Flat-Rolled Electrical Steel, 3.5 to 5 per cent Silicon Content, in Cut Lengths or Coils (A 379 - 54 T)

Accepted as Tentative, Revisions in:

Standard General Spec. for Flat-Rolled Electrical Steel (A 345 - 49)

Adopted as Standard, Revisions in:

Test for Alternating Current Core Loss and Permeability of Magnetic Materials (A 343 - 49)

Committee B-1 on Wires for Electrical Conductors:

Report presented in the absence of the chairman by C. E. Ambelang, and the following actions taken:

Accepted as Tentative:

Spec. for Soft or Annealed Coated Copper Conductors for Use in Hookup Wire for Electronic Equipment (B 286 - 54 T)

Accepted as Tentative, Revisions in:

Spec. for Soft or Annealed Copper Wire (B 3 - 53 T)
Spec. for Hard-Drawn Aluminum Wire for Electrical Purposes (B 230 - 53 T)

Adopted as Standard, Revisions in:

Spec. for Concentric-Lay-Stranded Aluminum Conductors, Hard-Drawn (B 231 - 53)
Spec. for Rolled Aluminum Rods (EC Grade) for Electrical Purposes (B 233 - 52)

Committee B-4 on Metals for Electrical Heating, Electrical Resistance, and Electronic Applications:

Report presented in the absence of the chairman by J. S. Pettibone, and the following actions taken:

Accepted as Tentative:

Spec. for Tungsten Wire Under 20 mils in Diameter (B 288 - 54 T)
Spec. for Molybdenum Wire Under 20 mils in Diameter (B 289 - 54 T)
Spec. for Round Wire for Use as Electron Tube Grid Laterals and Verticals (B 290 - 54 T)

Committee B-5 on Copper and Copper Alloys, Cast and Wrought:

Report presented by G. H. Harnden, chairman, and the following actions taken:

Accepted as Tentative:

Spec. for Copper-Zinc-Manganese Alloy (Manganese Brass) Sheet and Strip (B 291 - 54 T)
Spec. for Nickel-Tin Bronze Castings (B 292 - 54 T)

Accepted as Tentative, Revisions in:

Spec. for Copper-Nickel-Zinc Alloy (Nickel Silver), and Copper-Nickel Alloy Plate, Sheet, Strip, and Rolled Bar (B 122 - 52 T)
Spec. for Copper Rod, Bar, and Shapes (B 133 - 52 T)
Spec. for General Requirements for Wrought Seamless Copper and Copper-Alloy Pipe and Tube (B 251 - 53 T)

Adopted as Standard:

Spec. for Cartridge Brass Sheet, Strip, Plate, Bar, and Disks (B 19 - 52 T)
Spec. for Copper-Base Alloy Centrifugal Castings (B 271 - 52 T)
Rec. Practice for Tension Test Specimens for Copper-Base Alloys for Sand Castings (B 208 - 49 T)

Adopted as Standard, Revisions in:

Spec. for Copper-Base Alloys in Ingot Form for Sand Castings (B 30 - 49)
Spec. for Seamless Copper Pipe, Standard Sizes (B 42 - 52)
Spec. for Seamless Copper Tube, Bright Annealed (B 68 - 51)
Spec. for Seamless Copper Tube (B 75 - 52)
Spec. for Seamless Copper Water Tube (B 88 - 51): Covering (1) immediate adoption of revision of Section 5; and (2) adoption as standard of present tentative revision of Section 11(i).
Spec. for Copper-Silicon Alloy Plate and Sheet for Pressure Vessels (B 96 - 51)
Spec. for Copper-Silicon Alloy Plate, Sheet, Strip, and Rolled Bar for General Purposes (B 97 - 51)
Spec. for Copper-Silicon Alloy Rod, Bar, and Shapes (B 98 - 52)
Spec. for Copper-Silicon Alloy Wire for General Purposes (B 99 - 51)
Spec. for Rolled Copper-Alloy Bearing and Expansion Plates and Sheets for Bridge and Other Structural Uses (B 100 - 52)
Spec. for Copper and Copper-Base Alloy Forging Rod, Bar, and Shapes (B 124 - 52)
Spec. for Manganese Bronze Rod, Bar, and Shapes (B 138 - 52): Covering (1) immediate adoption of revision of Table I; and (2) adoption as standard of present tentative revision of Section 6.

Spec. for Leaded Red Brass (Hardware Bronze) Rod, Bar, and Shapes (B 140 - 52)

Spec. for Aluminum Bronze Rod, Bar and Shapes (B 150 - 52): Covering (1) immediate adoption of revision of Table I and Table II; and (2) adoption as standard of present tentative revision of Section 6.

Spec. for Copper Sheet, Strip, Plate, and Rolled Bar (B 152 - 52): Covering (1) immediate adoption of revision of Section 5(a); and (2) adoption as standard of present tentative revision of Table II.

Spec. for Phosphor Bronze Wire (B 159 - 52)

Spec. for Copper Bus Bar, Rod, and Shapes (B 187 - 52)

Spec. for Seamless Copper Bus Pipe and Tube (B 188 - 52)

Spec. for Copper-Nickel-Zinc Alloy (Nickel Silver) Wire (B 206 - 52)

Spec. for Copper Plates for Locomotive Fireboxes (B 11 - 49)

Spec. for Copper Rods for Locomotive Staybolts (B 12 - 52)

Spec. for Seamless Brass Boiler Tubes (B 14 - 49)

Spec. for Naval Brass Rod, Bar, and Shapes (B 21 - 52)

Spec. for Seamless Red Brass Pipe, Standard Sizes (B 43 - 52)

Spec. for Copper and Copper-Alloy Seamless Condenser Tubes and Ferrule Stock (B 111 - 52)

Spec. for Gilding Metal Strip (B 130 - 52)

Spec. for Gilding Metal Bullet Jacket Cups (B 131 - 51)

Spec. for Seamless Brass Tube (B 135 - 52)

Spec. for Copper-Alloy Condenser Tube Plates (B 171 - 52)

Committee B-8 on Electrodeposited Metallic Coatings:

Report presented in the absence of the chairman by J. S. Pettibone, and the following actions taken:

Accepted as Tentative, Revisions in:

Spec. for Electrodeposited Coatings of Nickel and Chromium on Steel (A 166 - 53 T)

Spec. for Electrodeposited Coatings of Lead on Steel (B 200 - 53 T)

Spec. for Chromate Finishes on Electrodeposited Zinc, Hot-Dipped Galvanized, and Zinc Die-Cast Surfaces (B 201 - 49 T)

Adopted as Standard:

Test for Local Thickness of Electrodeposited Coatings (A 219 - 51 T)

Adopted as Standard, Revisions in:

Rec. Practice for Preparation of High-Carbon Steel for Electroplating (B 242 - 53)

Spec. for Electrodeposited Coatings of Nickel and Chromium on Zinc and Zinc-Base Alloys (B 142 - 53)

Committee B-9 on Metal Powders and Metal Powder Products:

Report presented in the absence of the chairman by H. R. Biehl, and the following actions taken:

Accepted as Tentative:

Method for Subsieve Analysis of Granular Metal Powders by Air Classification (B 293 - 54 T)

Rec. Practice for Hardness Testing of Cemented Carbides (B 294 - 54 T)

Accepted as Tentative, Revisions in:

Spec. for Sintered Metal Powder Structural Parts from Bronze (B 255 - 51 T)

Adopted as Standard:

Rec. Practice for Evaluating Cemented Carbides for Apparent Porosity (B 276 - 52 T)

Committee C-3 on Chemical-Resistant Mortars:

Report presented by Beaumont Thomas, chairman, and the following actions taken:

Accepted as Tentative:

Test for Bond Strength of Chemical-Resistant Mortars (C 321 - 54 T)

Adopted as Standard:

Test for Chemical Resistance of Hydraulic-Cement Mortars (C 267 - 51 T)

Spec. for Sulfur Mortar (C 287 - 52 T)

Committee C-17 on Asbestos-Cement Products:

Report presented in the absence of the chairman by R. J. Painter, and accepted as a report of progress.

FIFTH SESSION—SYMPOSIUM ON COAL SAMPLING[4]

(*Symposium Continued from Second Session*)

MONDAY, JUNE 14, 8:00 P.M.

SESSION CHAIRMAN: PAST-PRESIDENT A. C. FIELDNER

CO-CHAIRMAN: W. M. BERTHOLF

- Introduction—A. C. Fieldner.
- A Test on a Slotted Revolving Cylinder Coal Sampler—A. O. Blatter, presented by the author.
- Tests of Accuracy of a Mechanical Coal Sampler—R. L. Coryell, F. J. Schwerd, and E. J. Parente, presented by Mr. Coryell.
- Tests of the Geary-Jennings Sampler at Cabin Creek—W. M. Bertholf and W. L. Webb, presented by Mr. Webb.
- The Variances of Reduction and Analysis—W. W. Anderson and M. L. Sutherland, presented by Miss Sutherland.
- Multi-Lot Sampling, The Accuracies in Sampling of Large Coal Shipments by Applications of the Variance Concept—T. A. Miskimen and R. S. Thurston, presented from manuscript by Mr. Miskimen.

SIXTH SESSION—SYMPOSIUM ON TEMPERATURE STABILITY OF ELECTRICAL INSULATING MATERIALS[5]

(*Symposium Continued from Third Session*)

MONDAY, JUNE 14, 8:00 P.M.

SESSION CHAIRMAN: L. B. SCHOFIELD

CO-CHAIRMAN: A. H. SCOTT

- Thermal Stability of Polyvinyl Chloride Insulating Compounds—R. C. Bartlett, presented from manuscript by the author.
- The Deflected Beam-Film Rupture Test Applied to Sheet Insulation—K. N. Mathes and H. I. Morgan, presented from manuscript by Mr. Mathes.
- A Method for Evaluation of the Thermal Aging Stability of Flexible Sheet Insulation—C. G. Currin and R. M. Plettner, presented by Mr. Currin.
- Effect of Elevated Temperature on Silicone Varnished Glass Fabric for Electrical Insulation—O. E. Anderson, presented from manuscript by the author.
- Heat Aging Characteristics of Insulating Varnishes—H. I. Morgan and K. N. Mathes, presented from manuscript by Mr. Morgan.

SEVENTH SESSION—WHAT STANDARDS MEAN TO US[6]

TUESDAY, JUNE 15, 9:30 A.M.

SESSION CHAIRMAN: J. J KANTER

Under the auspices of the Chicago General Committee on Arrangements through its Technical Program Committee headed by J. J. Kanter, a special session was held which evaluated various viewpoints on the significance and use of standards. The program included a broad introductory statement and discussion by prominent technical leaders representing consumer and producer interests and significant remarks from the standpoint of the Defense Department. The list of papers and speakers follows:

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[6] Published in the ASTM BULLETIN, No. 203, January, 1955, p. 41.

Introductory Remarks and Background—R. J. Painter, Executive Secretary, ASTM.

Specifications from the Consumer's Viewpoint—A. W. F. Green, Chief Metallurgist, Allison Div., General Motors Corp.

Specifications from the Producer's Viewpoint—A. O. Schaefer, Vice-President in Charge of Engineering and Manufacturing, The Midvale Co.

Materials Standards and the Department of Defense—Capt. C. R. Watts (U. S. Navy), Staff Director, Standardization, Office of Assistant Secretary of Defense (Supply and Logistics).

EIGHTH SESSION—REPORT SESSION

TUESDAY, JUNE 15, 11:30 A.M.

SESSION CHAIRMAN: K. B. WOODS

Committee C-2 on Magnesium Oxychloride and Magnesium Oxysulfate Cements:

Report presented in the absence of the chairman by L. C. Gilbert, and the following actions taken:

Accepted as Tentative, Revisions in:

Test for Ignition Loss and Active Calcium Oxide in Magnesium Oxide for Use in Magnesium Oxychloride Cements (C 247 - 52)

The committee withdrew from the report as preprinted the recommendation for revision of the Tentative Specifications for Oxychloride Magnesia (C 275 - 51 T).

Committee C-4 on Clay Pipe:

Report presented by R. G. Scott, secretary, and the following actions taken:

Adopted as Standard:

Methods of Testing Clay Pipe (C 301 - 52 T)

Rec. Practice for Installing Clay Sewer Pipe (C 12 - 51 T)

Spec. for Standard Strength Clay Sewer Pipe (C 13 - 50 T)

Spec. for Standard Strength Ceramic Glazed Clay Sewer Pipe (C 261 - 50 T)

Committee C-8 on Refractories:

Report presented in the absence of the chairman by L. C. Gilbert, and the following actions taken:

Accepted as Tentative, Revisions in:

Def. of Terms Relating to Refractories (C 71 - 51)

Spec. for Fireclay-Base Castable Refractories for Boiler Furnaces and Incinerators (C 213 - 51)

Adopted as Standard:

Test for Disintegration of Fireclay Refractories in an Atmosphere of Carbon Monoxide (C 288 - 52 T)

Adopted as Standard, Revisions in:

Test for Crushing Strength and Modulus of Rupture of Insulating Fire Brick at Room Temperature (C 93 - 46)

Committee C-13 on Concrete Pipe:

Report presented by R. R. Litehiser, chairman, and the following actions taken:

Accepted as Tentative, Revisions in:

Spec. for Concrete Sewer Pipe (C 14 - 52)

Spec. for Reinforced Concrete Sewer Pipe (C 75 - 52)

Spec. for Reinforced Concrete Culvert Pipe (C 76 - 52)

Spec. for Concrete Irrigation Pipe (C 118 - 52)

Adopted as Standard, Revisions in:

Spec. for Concrete Sewer Pipe (C 14 - 52)

Spec. for Reinforced Concrete Sewer Pipe (C 75 - 52)

Spec. for Reinforced Concrete Culvert Pipe (C 76 - 52)

Committee D-3 on Gaseous Fuels:

Report presented in the absence of the chairman by L. C. Gilbert, and the following action taken:

Adopted as Standard:

Method of Sampling Manufactured Gas (D 1247 – 52 T)

NINTH SESSION—LUNCHEON, PRESIDENT'S ADDRESS, HONORARY MEMBERSHIPS, AWARDS OF MERIT, 50- AND 40-YEAR MEMBERS, INTRODUCTION OF NEW OFFICERS

TUESDAY, JUNE 15, 12:00 NOON

CHAIRMAN: PAST-PRESIDENT HAROLD L. MAXWELL

About 325 were present at this annual luncheon session, including a number of ladies and visitors.

Awards of Merit:

The Chairman of the 1954 Award of Merit Committee, A. T. Goldbeck, read brief citations and presented the following to President Beard, who conferred on them, on behalf of the Board of Directors, the certificates of the Award of Merit:

Harvey Arthur Anderson
Benjamin Albert Anderton
James Aston
Robert Franklin Field
Oliver Mills Hayden
Earl Foster Kelley
Gordon Mabey Kline
Stewart Sylvanus Kurtz, Jr.
Ernest Edgar Thum
Sam Tour
Herbert Lucius Whittemore

Election of Officers:

Results of the letter ballot on election of new officers were announced by the Chairman of the Tellers' Committee, H. P. Hagedorn. The results were as follows:

For President, to serve for one year:
  N. L. Mochel, 1050 votes.
For Vice-President, to serve for two years:
  R. A. Schatzel, 1046 votes.
For Directors, to serve for three years:
  E. J. Albert, 1044 votes.
  John M. Campbell, 1043 votes.
  Paul V. Garin, 1045 votes.
  John H. Jenkins, 1042 votes.
  D. E. Parsons, 1047 votes.

The newly-elected members of the Board of Directors who were present were introduced, as were President-elect Mochel and Vice-President Schatzel, the latter two men responding briefly.

Presidential Address:

The annual President's Address was presented by L. C. Beard, Jr., his subject being "Plain Talk." This address is printed in the July ASTM BULLETIN.

Award of Honorary Memberships:

The Executive Secretary read citations for the following two members who had been elected by the Board of Directors to Honorary Membership in the Society:

Kenneth G. Mackenzie
Louis H. Winkler

Dr. Beard presented the certificates to Messrs. Mackenzie and Winkler.

Frank E. Richart Award:

This award, established through a gift

from Mrs. F. E. Richart, recognizes outstanding contributions in the field of concrete and concrete aggregates. The first recipient was Albert T. Goldbeck, Engineering Director, National Crushed Stone Assn., who was presented to the President by J. H. Gilkey, chairman of Frank E. Richart Award Committee.

Report of the Board of Directors:

R. J. Painter, Executive Secretary, presented a brief résumé of the Report of the Board of Directors.

Recognition of 50- and 40-year Members, Special Presentations:

The Executive Secretary read the names of nine members, both individual and company, who had been continuously affiliated with the Society for 50 years. Certificates to that effect were presented. The procedure was repeated for twenty-two 40-year members. A complete list of the 50- and 40-year members appears in the July, 1954, ASTM BULLETIN.

Chairman Maxwell then presented the Past-President's pin to retiring President L. C. Beard, Jr. Mention was made that this meeting brings to a close for L. J. Markwardt eight consecutive years on the Board of Directors, as Director, Vice-President, President, and Past-President. Recognition was also given to J. W. Bolton, E. O. Slater, Stanton Walker, and F. P. Zimmerli as retiring directors.

TENTH SESSION—SYMPOSIUM ON ODOR[7]

TUESDAY, JUNE 15, 2:30 P.M.

SESSION CHAIRMAN: AMOS TURK

Introduction—Amos Turk.

Odor: A Proposal for Some Basic Definitions—Edward Sagarin, presented from manuscript by Mr. George Kolar.

Catalytic Method of Measuring Hydrocarbon Concentrations in Industrial Exhaust Fumes—R. J. Ruff, presented from manuscript by Mr. Paul Goodall.

The Design, Construction, and Use of an Odor Test Room—Nicholas Deininger and Russell W. McKinley, presented from manuscript by Mr. McKinley.

(*Symposium Continued in Fifteenth Session*)

ELEVENTH SESSION—SYMPOSIUM ON PERMEABILITY OF SOILS[8]

TUESDAY, JUNE 15, 2:30 P.M.

SESSION CHAIRMAN: A. W. JOHNSON

Principles of Permeability Testing of Soils—Donald M. Burmister, presented from manuscript by the author.

Water Movement Through Porous Hydrophilic Systems Under Capillary, Electric, and Thermal Potentials—Hans F. Winterkorn, presented from manuscript by the author.

Permeability Test for Sands—T. Y. Chu and D. T. Davidson, presented from manuscript by Mr. Chu.

Low-Head Permeameter for Granular Materials—E. G. Yemington, presented from manuscript by Mr. E. S. Barber.

(*Symposium Continued in Seventeenth Session*)

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[7] Issued as separate technical publication *ASTM STP No. 164.*

[8] Issued as separate technical publication *ASTM STP No. 163.*

TWELFTH SESSION—BITUMINOUS MATERIALS

TUESDAY, JUNE 15, 4:00 P.M.

SESSION CHAIRMAN: C. A. CARPENTER

Papers:

Evaluating the Specific Gravity of Aggregates for Use in Bituminous Mixtures—W. C. Ricketts, J. C. Sprague, D. D. Tabb, and J. L. McRae, presented by Mr. Sprague.

A Simple Fractional Distillation Test for Creosote—H. L. Stasse, presented from manuscript by the author.

Committee D-4 on Road and Paving Materials:

Report presented by B. A. Anderton, secretary, and the following actions taken:

Accepted as Tentative, Revisions in:

Spec. for Hot-Mixed, Hot-Laid Asphaltic Concrete for Base and Surface Courses (D 947 - 52 T)

Test for Bitumen Content of Paving Mixtures by Centrifuge (D 1097 - 50 T)

Spec. for Crushed Stone, Crushed Slag, and Gravel for Water-Bound Macadam Base and Surface Courses of Pavements (D 694 - 49)

Adopted as Standard:

Test for Effect of Water on Cohesion of Compacted Bituminous Mixtures (D 1075 - 49 T)

Spec. for Asphaltic Mixtures for Sheet Asphalt Pavements (D 978 - 52 T)

Spec. for Fine Aggregate for Sheet Asphalt and Bituminous Concrete Pavements (D 1073 - 51 T)

Spec. for Crushed Stone, Crushed Slag, and Gravel for Bituminous Concrete Base and Surface Courses of Pavements (D 692 - 51 T)

Test for Soft Particles in Coarse Aggregates (C 235 - 49 T) (Jointly with Committee C-9)

Adopted as Standard, Revisions in:

Spec. for Standard Sizes of Coarse Aggregate for Highway Construction (D 448 - 49)

Spec. for Crushed Stone and Crushed Slag for Bituminous Macadam Base and Surface Courses of Pavements (D 693 - 49)

Spec. for Crushed Stone, Crushed Slag, and Gravel for Water-Bound Macadam Base and Surface Courses of Pavements (D 694 - 49)

Also included in the preprinted report of Committee D-4 were recommendations for (1) adoption as standard of Tentative Methods of Sampling Bituminous Materials (D 140 - 52 T); and (2) adoption as standard of tentative revisions of Standard Methods of Testing Emulsified Asphalts (D 244 - 49). These methods are also under the jurisdiction of Committee D-8 and that committee has not as yet concurred in these recommendations.

Committee D-16 on Industrial Aromatic Hydrocarbons and Related Materials:

Report presented by D. F. Gould, chairman, and accepted as a report of progress.

THIRTEENTH SESSION—REPORT SESSION

TUESDAY, JUNE 15, 4:30 P.M.

SESSION CHAIRMAN: G. H. HARNDEN

Committee A-5 on Corrosion of Iron and Steel:

Report presented by A. P. Jahn, chairman, and the following actions taken:

Accepted as Tentative, Revisions in:

Spec. for Zinc-Coated Steel Wire Strand ("Galvanized" and Class A ("Extra Galvanized")) (A 122 - 52 T)

Spec. for Zinc-Coated Steel Wire Strand (Class B and Class C Coatings) (A 218 - 52 T)

Adopted as Standard:

Test for Local Thickness of Electrodeposited Coatings (A 219 - 51 T)

Adopted as Standard, Revisions in:

Test for Weight and Composition of Coating on Long Terne Sheet by the Triple Spot Test (A 309 - 49)

The committee withdrew from the report as preprinted the recommendation for revision and reversion to tentative of the Standard Specifications for Zinc-Coated (Galvanized) Iron or Steel Tie Wires (A 112 - 33).

Committee B-2 on Non-Ferrous Metals and Alloys:

Report presented by B. W. Gonser, chairman, and accepted as a report of progress.

Committee B-7 on Light Metals and Alloys, Cast and Wrought:

Report presented by I. V. Williams, chairman, and the following actions taken:

Accepted as Tentative, Revisions in:

Spec. for Aluminum-Base Alloy Sand Castings (B 26 – 52 T)
Spec. for Magnesium-Base Alloy Forgings (B 91 – 49 T)
Spec. for Aluminum-Base Alloy Permanent Mold Castings (B 108 – 52 T)
Spec. for Aluminum and Aluminum-Alloy Sheet and Plate for Pressure Vessel Applications (B 178 – 53 T)
Spec. for Aluminum and Aluminum-Alloy Sheet and Plate (B 209 – 53 T)
Spec. for Aluminum-Alloy Drawn Seamless Tubes (B 210 – 53 T)
Spec. for Aluminum and Aluminum-Alloy Bars, Rods, and Wire (B 211 – 53 T)
Spec. for Aluminum and Aluminum-Alloy Extruded Bars, Rods, and Shapes (B 221 – 53 T)
Spec. for Aluminum-Alloy Extruded Tubes (B 235 – 53 T)
Spec. for Aluminum-Alloy Pipe (B 241 – 53 T)
Spec. for Aluminum-Alloy Die Forgings (B 247 – 50 T)
Spec. for Aluminum and Aluminum-Alloy Bars, Rods, and Shapes for Pressure Vessel Applications (B 273 – 53 T)
Spec. for Aluminum and Aluminum-Alloy Pipe and Tube for Pressure Vessel Applications (B 274 – 53 T)

Committee D-5 on Coal and Coke:

Report presented by W. W. Anderson, chairman, and the following actions taken:

Accepted as Tentative, Revisions in:

Test for Free-Swelling Index of Coal (D 720 – 46)
Methods of Laboratory Sampling and Analysis of Coal and Coke (D 271 – 48)

Committee E-3 on Chemical Analysis of Metals:

Report presented by Arba Thomas, vice-chairman, and accepted as a report of progress.

FOURTEENTH SESSION—GILLETT MEMORIAL LECTURE

TUESDAY, JUNE 15, 5:00 P.M.

SESSION CHAIRMAN: PRESIDENT L. C. BEARD, JR.

Third Gillett Memorial Lecture:

President Beard called upon Mr. Clarence E. Sims of Battelle Memorial Inst., who remarked upon the establishment of the H. W. Gillett Memorial Lecture. This lecture is sponsored jointly by the ASTM and the Battelle Memorial Inst. to perpetuate the memory of Horace W. Gillett, one of America's leading technologists, the first Director of Battelle Memorial Inst., and for many years a very active worker in the Society, through the presentation of a lecture on a subject pertaining to the development, test, evaluation, and application of metals.

Richard L. Templin, Assistant Director of Research and Chief Engineer of Tests, Aluminum Company of America, was selected to prepare and present this lecture. In Mr. Templin's absence as the result of a recent serious illness, Mr. Francis M. Howell, Chief of the Mechanical Testing Division of the Aluminum Research Laboratories, presented the lecture on "Fatigue of Aluminum." Mr. Howell presented a brief description of the phenomenon of fatigue of metals and a discussion of the mechanism of fatigue failure. The various factors that affect the fatigue strength of metals, specifically the aluminum alloys, were described in detail. Also covered were such factors as alloy composition, heat treatment, grain size, residual stresses, design fabrication, and environment.

President Beard expressed appreciation to Mr. Howell for delivering the lecture and, in Mr. Templin's absence, presented to him on behalf of the Society the H. W. Gillett Memorial Lecture Certificate requesting that he in turn deliver it to Mr. Templin.

FIFTEENTH SESSION—SYMPOSIUM ON ODOR[7]

(*Symposium Continued from Tenth Session*)

TUESDAY, JUNE 15, 8:00 P.M.

SESSION CHAIRMAN: L. C. MCCABE

Organoleptic Appraisal of Three-Component Mixtures—A. Haldane Gee, presented by the author.

Odor Pollution from an Official's Viewpoint—C. W. Gruber, presented by the author.

Odor Control Methods: A Critical Review—Amos Turk, presented from manuscript by the author.

SIXTEENTH SESSION—FATIGUE

TUESDAY, JUNE 15, 8:00 P.M.

SESSION CHAIRMAN: W. T. LANKFORD

Committee E-9 on Fatigue:

Report presented by R. E. Peterson, chairman, and accepted as a report of progress.

Papers:

Softening of Certain Cold-Worked Metals Under the Action of Fatigue Loads—N. H. Polakowski and A. Palchoudhuri, presented by Mr. Polakowski.

Metallographic Aspects of Fatigue Behavior of Aluminum—M. S. Hunter and W. G. Fricke, Jr., presented from manuscript by Mr. Fricke.

The Influence of Test Temperature and Grain Size on the Fatigue of Notch Sensitivity of "Refractaloy-26"—P. R. Toolin, presented from manuscript by the author.

An Experimental Study of the Influence of Fluctuating Stress Amplitude on Fatigue Life of 75S-T6 Aluminum—H. T. Corten, G. M. Sinclair, and T. J. Dolan, presented by Mr. Corten.

Effect of Range of Stress and Prestrain on the Fatigue Properties of Titanium—J. P. Romualdi and E. D'Appolonia, presented from manuscript by Mr. D'Appolonia.

(*Continued in Eighteenth and Twenty-second Sessions*)

SEVENTEENTH SESSION—SYMPOSIUM ON PERMEABILITY OF SOILS[8]

(*Symposium Continued from Eleventh Session*)

TUESDAY, JUNE 15, 8:00 P.M.

SESSION CHAIRMAN: HAROLD ALLEN

The Permeability of Compacted Fine Grained Soils—T. W. Lambe, presented from manuscript by Mr. E. S. Barber.

The Permeability and Settlement of Laboratory Specimens of Sand and Sand-Gravel Mixtures—Chester W. Jones, presented by the author.

Measurement of the Hydraulic Conductivity of Soil, In Place—Don Kirkham, presented from manuscript by the author.

Measurement of Permeabilities in Ground-Water Investigations—W. O. Smith, presented from manuscript by the author.

Selected References on Permeability—A. I. Johnson. (Presented by title.)

Summary—E. S. Barber.

EIGHTEENTH SESSION—FATIGUE

(Continued from Sixteenth Session)

WEDNESDAY, JUNE 16, 9:15 A.M.

SESSION CHAIRMAN: T. J. DOLAN

Fatigue Strength of 14S-T4 Aluminum Alloy Subjected to Biaxial Stresses—Robert Bundy and J. Marin, presented by Mr. Bundy.

A Failure Criterion for Multi-Axial Fatigue Stresses—F. B. Stulen and H. N. Cummings, presented by Mr. Cummings.

Dynamic Creep and Rupture Properties of an Aluminum Alloy Under Axial Static and Fatigue Stress—F. W. DeMoney and B. J. Lazan, presented by Mr. Lazan.

Experiments in Fatigue Under Ranges of Stress in Torsion and Axial Load from Tension to Extreme Compression—W. N. Findley, presented from manuscript by the author.

(Continued in Twenty-second Session)

NINETEENTH SESSION—SOILS

WEDNESDAY, JUNE 16, 9:15 A.M.

SESSION CHAIRMAN: E. J. KILCAWLEY

Papers:

Study and Development of Methods for Determining In-Place Density of Cohesionless Soils—Donald F. Griffin, presented from manuscript by the author.

Investigation of the Effect of Transient Loading on the Strength and Deformation Characteristics of Saturated Sands—H. B. Seed and R. Lundgren, presented from manuscript by Mr. George Sowers.

Piles Subjected to Lateral Thrust[9]

Part I—H. G. Mason and J. A. Bishop, presented by Mr. Mason.

Part II—L. A. Palmer and P. P. Brown, presented by Mr. Palmer.

Committee D-18 on Soils for Engineering Purposes:

Report presented by E. J. Kilcawley, chairman, and the following actions taken:

Accepted as Tentative, Revisions in:

Test for Liquid Limit of Soils (D 423 - 39)

Test for Plastic Limit and Plasticity Index of Soils (D 424 - 39)

Method of Mechanical Analysis of Soils (D 422 - 51)

The revisions in these standards consisted in a complete rewriting, and with their acceptance for publication as tentative, the standards have been withdrawn.

Adopted as Standard:

Test for Amount of Material in Soils Finer than the No. 200 Sieve (D 1140 - 50 T)

C. A. Hogentogler Award:

Established by the committee in honor of its First Chairman and given in recognition of a paper of outstanding merit on soils for engineering purposes presented before the Society, the first presentation of this award was made to A. A. Wagner, Bureau of Reclamation, Denver, Colo., for his paper on "Lateral Load Tests on Piles for Design Information," presented at the 1953 Annual Meeting and published in the Symposium on Lateral Load Tests on Piles, STP No. 154.

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[9] Issued as a supplement to the Symposium on Lateral Load Tests on Piles, *ASTM STP No. 154A*.

TWENTIETH SESSION—REPORT SESSION

WEDNESDAY, JUNE 16, 11:30 A.M.

SESSION CHAIRMAN: D. E. PARSONS

Committee C-14 on Glass and Glass Products:

Report presented in the absence of the chairman by L. C. Gilbert, and the following actions taken:

Adopted as Standard:

Test for Resistance of Glass Containers to Chemical Attack (C 225 - 49 T)

Committee C-16 on Thermal Insulating Materials:

Report presented in the absence of the chairman by L. C. Gilbert, and the following actions taken:

Accepted as Tentative:

Spec. for Cellular Glass Insulating Block (C 343 - 54 T)
Spec. for Calcium Silicate Block-Type Thermal Insulation (C 344 - 54 T)
Spec. for Calcium Silicate Thermal Insulation for Pipes (C 345 - 54 T)

Adopted as Standard:

Spec. for Mineral Wool Blanket Insulation (Metal-Mesh Covered) (Industrial Type) (C 263 - 51 T)
Spec. for Mineral Wool Blanket-Type Pipe Insulation (C 280 - 51 T)

Adopted as Standard, Revisions in:

Test for Compressive Strength of Preformed Block Type Thermal Insulation (C 165 - 45)

Tentative Withdrawn:

Test for Water Vapor Permeability of Sheet Materials Used in Connection with Thermal Insulation (C 214 - 48 T)

Committee C-21 on Ceramic Whiteware:

Report presented in the absence of the chairman by L. C. Gilbert, and the following actions taken:

Accepted as Tentative, Revisions in:

Def. of Terms Relating to Ceramic Whiteware (C 242 - 50 T)

Committee C-22 on Porcelain Enamel:

Report presented by W. N. Harrison, chairman, and the following actions taken:

Accepted as Tentative:

Test for 45-deg Specular Gloss of Porcelain Enamels (C 346 - 54 T)
Test for Reflectivity and Coefficient of Scatter of White Porcelain Enamels (C 347 - 54 T)

Adopted as Standard:

Test for Resistance of Porcelain Enameled Utensils to Boiling Acid (C 283 - 51 T)
Test for Sieve Analysis of Wet Milled and Dry Milled Porcelain Enamel (C 285 - 52 T)

Committee E-1 on Methods of Testing:

Report presented by P. J. Smith, secretary, and the following actions taken:

Accepted as Tentative:

Method for Rapid Indentation Hardness Testing of Metallic Materials (E 103 - 54 T)

Accepted as Tentative, Revisions in:

Methods of Tension Testing of Metallic Materials (E 8 - 52 T)
Test for Brinell Hardness of Metallic Materials (E 10 - 50 T)
Spec. for ASTM Hydrometers (E 100 - 53 T)
Def. of Terms Relating to Methods of Testing (E 6 - 36)

Adopted as Standard, Revisions in:

Spec. for ASTM Thermometers (E 1 - 53)
Test for Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials (E 18 - 42)

Accepted for Publication as Information Only:

Specifications for Apparatus for the Determination of Water by Distillation

Committee E-5 on Fire Tests of Materials and Construction:

Report presented by R. C. Corson, secretary, and the following actions taken:

Accepted as Tentative, Revisions in:

Methods of Fire Tests of Building Construction and Materials (E 119 - 53)

Adopted as Standard, Revisions in:

Methods of Fire Tests of Building Construction and Materials (E 119 - 53): Covering (1) immediate adoption of revision of the Introduction; and (2) adoption as standard of present tentative revision of Sections 9 and 26.

Committee E-11 on Quality Control of Materials:

Report presented by H. F. Dodge, chairman, and accepted as a report of progress.

TWENTY-FIRST SESSION—EFFECT OF TEMPERATURE

WEDNESDAY, JUNE 16, 2:00 P.M.

SESSION CHAIRMAN: VICE-PRESIDENT N. L. MOCHEL

Joint Committee on Effect of Temperature on the Properties of Metals:

Report presented by F. B. Foley, chairman, and accepted as a report of progress.

Papers:

The Strength of Carbon Steels for Elevated Temperature Applications—R. F. Miller, presented by the author.

Statistical Evaluation of the Creep-Rupture Properties of Four Heat-Resistant Alloys in Sheet Form—A. I. Rush and J. W. Freeman, presented by Mr. Rush.

Elevated Temperature Fatigue Properties of Several High-Temperature Sheet Materials—D. C. Goldberg and J. J. Lombardo, presented from manuscript by Mr. Goldberg.

Thermal Shock Testing Procedure—A. W. F. Green, K. Lampson, and T. Tsareff, presented from manuscript by Mr. Lampson.

TWENTY-SECOND SESSION—FATIGUE

(*Continued from Sixteenth and Eighteenth Sessions*)

WEDNESDAY, JUNE 16, 2:00 P.M.

SESSION CHAIRMAN: R. E. PETERSON

SECRETARY: W. T. LANKFORD

A Simplified Statistical Procedure for Obtaining Design-Level Fatigue Curves—E. H. Schuette, presented by the author.

An Appraisal of the Prot Method of Fatigue Testing—H. T. Corten, Todor Dimoff, and T. J. Dolan, presented by Mr. Dolan.

Investigations Concerning the Fatigue of Aircraft Structures—Robert A. Carl and Thomas J. Wegeng, presented by Mr. Carl.

On Fatigue Tests Under Progressive Stress, a Theory of Fatigue of Metals and a Quick Method for Determining the Fatigue Limit—Nobusuke Enomoto. (Presented by title.)[10]

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[10] To be published in *Proceedings*, Am. Soc. Testing Mats., Vol. 55 (1955).

TWENTY-THIRD SESSION—SIGNIFICANCE OF TESTS OF CONCRETE[11]

WEDNESDAY, JUNE 16, 2:00 P.M.

SESSION CHAIRMAN: L. E. GREGG

Mixing and Curing Water for Concrete—W. J. McCoy, presented from manuscript by the author.

Petrographic Examination of Concrete Aggregates—Richard C. Mielenz, presented from manuscript by the author.[12]

Significance of Tests and Properties of Mineral Admixtures—H. S. Meissner, presented from manuscript by the author.

Air-Entraining Admixtures—C. E. Wuerpel, presented from manuscript by the author.

Setting Time of Concrete—E. W. Scripture, Jr., presented from manuscript by Mr. S. W. Benedict.

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[11] To be issued as a separate technical publication.

[12] To be included in the Significance of Tests of Concrete volume. Also published in this volume, p. 1188.

TWENTY-FOURTH SESSION—REPORT SESSION

WEDNESDAY, JUNE 16, 4:00 P.M.

SESSION CHAIRMAN: M. VAN LOO

Committee C-1 on Cement:

Report presented by R. R. Litehiser, chairman, and the following actions taken:

Accepted as Tentative:

Spec. for Portland-Pozzolan Cement (C 340 - 54 T)
Test for Heat of Hydration of Portland Cement (Short Method) (C 186 - 54 T)

Accepted as Tentative, Revisions in:

Spec. for Air-Entraining Additions for Use in the Manufacture of Air-Entraining Portland Cement (C 226 - 52 T)
Test for Calcium Sulfate in Hydrated Portland Cement Mortar (C 265 - 51 T)
Test for Autoclave Expansion of Portland Cement (C 151 - 53)

Adopted as Standard:

Spec. for Natural Cement (C 10 - 52 T)

Adopted as Standard, Revisions in:

Test for Autoclave Expansion of Portland Cement (C 151 - 53)

Committee C-11 on Gypsum:

Report presented by G. W. Josephson, chairman, and the following actions taken:

Accepted as Tentative:

Spec. for Gypsum Concrete (C 317 - 54 T)

Adopted as Standard, Revisions in:

Spec. for Gypsum Wallboard (C 36 - 52)
Methods of Testing Gypsum and Gypsum Products (C 26 - 52)
Spec. for Gypsum Partition Tile or Block (C 52 - 41)
Spec. for Gypsum Sheathing Board (C 79 - 52)
Spec. for Gypsum Lath (C 37 - 50)

Committee C-15 on Manufactured Masonry Units:

Report presented by M. H. Allen, secretary, and the following actions taken:

Accepted as Tentative, Revisions in:

Methods of Sampling and Testing Concrete Masonry Units (C 140 - 52)

Adopted as Standard:

Spec. for Structural Clay Facing Tile (C 212 - 52 T)
Spec. for Chemical-Resistant Masonry Units (C 279 - 52 T)

The committee withdrew from the report as preprinted the proposed tentative Specification for Brick-Block Units Made from Clay or Shale.

Committee D-1 on Paint, Varnish, Lacquer, and Related Products:

Report presented by W. T. Pearce, chairman, and the following actions taken:

Accepted as Tentative:

Test for Fineness of Grind of Printing Inks by the Production Grindometer (D 1316 - 54 T)
Test for Flash Point of Volatile Solvents by the Tag Open-Cup Apparatus (D 1310 - 54 T)
Test for Phthalic Anhydride Content of Alkyd Resins and Esters Containing Other Dibasic Acids (Gravimetric) (D 1306 - 54 T)
Test for Phthalic Anhydride Content of Alkyd Resins and Esters Containing Other Dibasic Acids (Spectrophotometric) (D 1307 - 54 T)
Test for Viscosity Reduction Power of Hydrocarbon Solvents (D 1311 - 54 T)
Test for Apparent Free Phenols in Synthetic Phenolic Resins or Solutions Used for Coating Purposes (D 1312 - 54 T)
Test for Acid Number of Bleached Lac and Bleached Lac Varnish (D 29 - 54 T)

Accepted as Tentative, Revisions in:

Test for Kauri-Butanol Value of Hydrocarbon Solvents (D 1133 - 50 T)
Test for Purity of Acetone and Methyl Ethyl Ketone (D 1154 - 51 T)
Method for Evaluating Resistance to Blistering of Paints on Metal When Subjected to Immersion or Other Exposure to Moisture or Liquids (D 714 - 45)

Adopted as Standard:

Spec. for Methanol (Methyl Alcohol) (D 1152 - 51 T)
Test for Specific Gravity of Pigments (D 153 - 52 T)
Water Immersion Test of Organic Coatings on Steel (D 870 - 51 T)

Laboratory Test for Degree of Resistance of Traffic Paint to Bleeding (D 969 - 52 T)
Test for Viscosity of Paints, Varnishes, and Lacquers by Ford Viscosity Cup (D 1200 - 52 T)
Test for Color of Clear Liquids (Platinum-Cobalt Scale) (D 1209 - 52 T)
Test for Fineness of Dispersion of Pigment-Vehicle Systems (D 1210 - 52 T)
Methods for Measurement of Wet Film Thickness of Paint, Varnish, Lacquer, and Related Products (D 1212 - 52 T)
Test for Crushing Resistance of Glass Spheres (D 1213 - 52 T)
Test for Sieve Analysis of Glass Spheres (D 1214 - 52 T)

Adopted as Standard, Revisions in:

Methods of Testing Drying Oils (D 555 - 53)

Accepted for Publication as Information Only:

Specifications for Raw Safflower Oil

Committee D-6 on Paper and Paper Products:

Report presented by W. R. Willets, chairman, and the following actions taken:

Adopted as Standard:

Test for Flat Crush of Corrugated Paperboard (D 1225 - 52 T)
Test for Water Resistance of Paper, Paperboard, and Other Sheet Materials by the Dry-Indicator Method (D 779 - 52 T), with editorial revision in Section 7 covering deletion of "10 or."
Test for Ply Adhesion of Paper (D 825 - 52 T), with editorial revision of the new Section 2 covering deletion of "5 to."
Test for Zinc and Cadmium in Paper (D 1224 - 52 T)

Committee D-10 on Shipping Containers:

Report presented in the absence of the chairman by L. C. Gilbert, and accepted as a report of progress.

Committee D-9 on Electrical Insulating Materials:

Report presented by W. A. Zinzow, vice-chairman, and the following actions taken:

Accepted as Tentative:

Test for Water in Insulating Oils by Extraction (D 1315 - 54 T)

Accepted as Tentative, Revisions in:

Test for Molded Materials Used for Electrical Insulation (D 48 - 52 T)
Method of Testing Electrical Insulating Oil (D 117 - 53 T)
Test for Electrical Resistance of Insulating Materials (D 257 - 52 T)
Methods of Testing Varnished Cloths and Varnished Cloth Tapes Used for Electrical Insulation (D 295 - 52 T)
Test for Sludge Formation in Mineral Transformer Oil (D 670 - 42 T). The revision consists of revising the Sludge Accumulation Test (Method A) and publishing it as a separate method (D 1314 - 54 T). The High-Pressure Oxidation Test (Method B) is being adopted as standard and published as a separate method (D 1313 - 54)
Spec. for Vulcanized Fibre Sheets, Rods and Tubes Used for Electrical Insulation (D 710 - 52 T)
Rec. Practice for the Purchase of Uninhibited Mineral Oil for Use in Transformers and in Oil Circuit Breakers (D 1040 - 49 T)
Test for Insulation Resistivity of Electrical Insulating Oils of Petroleum Origin (D 1169 - 52 T)
Spec. for Enclosures and Servicing Units for Tests Above and Below Room Temperature (D 1197 - 52 T) (Jointly with Committee D-20)
Spec. for Phenolic Molding Compounds (D 700 - 52 T)
Methods of Testing Sheet and Plate Materials Used for Electrical Insulation (D 229 - 49)
Methods of Testing Laminated Tubes Used for Electrical Insulation (D 348 - 52)
Methods of Testing Laminated Round Rods Used for Electrical Insulation (D 349 - 52)
Test for Power Factor and Dielectric Constant of Electrical Insulating Oils of Petroleum Origin (D 924 - 49)
Test for Water Absorption of Plastics (D 570 - 42). This represents approval of the recommendation submitted by Committee D-20 to the Administrative Committee on Standards since this method is under joint jurisdiction of the two committees.

Adopted as Standard:

Spec. for Natural Block Mica and Mica Films Suitable for Use in Mica-Dielectric Capacitors (D 748 - 52 T)
Test for Sludge Formation in Mineral Transformer Oil (D 670 - 42 T). Method B was revised and adopted as standard as a separate method (D 1313 - 54).

Adopted as Standard, Revisions in:

Test for Power Factor and Dielectric Constant of Natural Mica (D 1082 – 51)
Methods of Conditioning Plastics and Electrical Insulating Materials for Testing (D 618 – 53) (Jointly with Committee D-20)

The committee withdrew from the report as preprinted the recommendation for adoption as standard of the Tentative Spec. for Orange Shellac and Other Indian Lacs for Electrical Insulation (D 784 – 52 T).

TWENTY-FIFTH SESSION—REPORT SESSION

WEDNESDAY, JUNE 16, 4:00 P.M.

SESSION CHAIRMAN: PAST-PRESIDENT H. L. MAXWELL

Committee A-1 on Steel:

Report presented by H. B. Oatley, chairman, and the following actions taken:

Accepted as Tentative:

Spec. for High Strength Low Alloy Cold-Rolled Steel Sheets and Strip (A 374 – 54 T)
Spec. for High Strength Low Alloy Hot-Rolled Steel Sheet and Strip (A 375 – 54 T)
Spec. for Seamless Austenitic Steel Pipe for High-Temperature Central Station Service (A 376 – 54 T)

Accepted as Tentative, Revisions in:

Spec. for General Requirements for Delivery of Rolled Steel Plates, Shapes, Sheet Piling and Bars for Structural Use (A 6 – 53 T)
Spec. for Billet Steel Bars for Concrete Reinforcement (A 15 – 52 T)
Spec. for Rail Steel Bars for Concrete Reinforcement (A 16 – 52 T)
Spec. for Welded and Seamless Steel Pipe (A 53 – 52 T)
Spec. for Seamless Steel Boiler Tubes (A 83 – 52 T)
Spec. for Electric-Resistance-Welded Steel Pipe (A 135 – 51 T)
Spec. for Axle-Steel Bars for Concrete Reinforcement (A 160 – 52 T)
Spec. for Seamless Low-Carbon and Carbon-Molybdenum Steel Still Tubes for Refinery Service (A 161 – 53 T)
Spec. for Electric-Resistance-Welded Steel and Open-Hearth Iron Boiler Tubes (A 178 – 53 T)
Spec. for Cold-Drawn Low-Carbon Steel Heat-Exchanger and Condenser Tubes (A 179 – 53 T)
Spec. for Welded Steel Wire Fabric for Concrete Reinforcement (A 185 – 53 T)
Spec. for Seamless Steel Boiler Tubes for High-Pressure Service (A 192 – 51 T)
Spec. for Seamless Cold-Drawn Intermediate Alloy-Steel Heat-Exchanger and Condenser Tubes (A 199 – 53 T)
Spec. for Seamless Intermediate Alloy-Steel Still Tubes for Refinery Service (A 200 – 53a T)
Spec. for Seamless Carbon-Molybdenum Alloy-Steel Boiler and Superheater Tubes (A 209 – 51 T)
Spec. for Medium-Carbon Seamless Steel Boiler and Superheater Tubes (A 210 – 52 T)
Spec. for High Tensile Strength Carbon-Silicon Steel Plates for Boilers and Other Pressure Vessels (A 212 – 53 T)
Spec. for Seamless Alloy-Steel Boiler, Superheater and Heat Exchanger Tubes (A 213 – 53 T)
Spec. for Electric-Resistance-Welded Steel Heat-Exchanger and Condenser Tubes (A 214 – 53 T)
Spec. for Electric-Resistance-Welded Steel Boiler and Superheater Tubes for High-Pressure Service (A 226 – 53 T)
Spec. for Welded Austenitic Stainless Steel for Boiler, Superheater, Heat Exchanger and Condenser Tubes (A 249 – 53a T)
Spec. for Electric-Resistance-Welded Carbon-Molybdenum Alloy-Steel Boiler and Superheater Tubes (A 250 – 53 T)
Spec. for Welded and Seamless Open-Hearth Iron Pipe (A 253 – 51 T)
Spec. for Copper Brazed Steel Tubing (A 254 – 51 T)
Spec. for Steel Plates for Pressure Vessels for Service at Low Temperatures (A 300 – 53 T)
Spec. for Chromium-Molybdenum Steel Plates for Boilers and Other Pressure Vessels (A 301 – 53 T)
Spec. for Seamless and Welded Austenitic Stainless Steel Pipe (A 312 – 51 T) (Jointly with Committee A-10)
Spec. for Seamless and Welded Steel Pipe for Low-Temperature Service (A 333 – 50 T)

Spec. for Seamless and Welded Steel Tubes for Low-Temperature Service (A 334 – 51 T)
Methods and Definitions for Mechanical Testing of Steel Products (A 370 – 53 T)
Spec. for Open-Hearth Carbon-Steel Rails (A 1 – 53)

Adopted as Standard:

Spec. for Open-Hearth Steel Girder Rails of Plain, Grooved, and Guard Types (A 2 – 49 T)
Spec. for Low-Carbon Steel Joint Bars (A 3 – 49 T)
Spec. for Structural Nickel Steel (A 8 – 52a T)
Spec. for Soft Steel Track Spikes (A 65 – 49 T)
Spec. for Steel Screw Spikes (A 66 – 49 T)
Spec. for Structural Silicon Steel (A 94 – 52 T)
Spec. for Structural Steel for Locomotives and Cars (A 113 – 52 T)
Spec. for Carbon-Steel Forgings for General Industrial Use (A 235 – 52 T)
Spec. for Alloy-Steel Forgings for General Industrial Use (A 237 – 52 T)
Spec. for Carbon and Alloy-Steel Ring and Disk Forgings (A 243 – 51 T)
Spec. for Carbon-Steel Seamless Drum Forgings (A 266 – 51 T)
Spec. for Low and Intermediate Tensile Strength Carbon-Steel Plates of Structural Quality (Plates 2 in. and Under in Thickness) (A 283 – 52 T)
Spec. for Carbon and Alloy-Steel Forgings for Magnetic Retaining Rings for Turbine Generators (A 288 – 50 T)
Spec. for Alloy-Steel Forgings for Nonmagnetic Coil Retaining Rings for Turbine Generators (A 289 – 52 T)
Spec. for Carbon and Alloy-Steel Forgings for Rings for Reduction Gears (A 290 – 52 T)
Spec. for Steel Sheet Piling (A 328 – 52 T)
Spec. for Heat-Treated Steel Tires (A 329 – 50 T)
Method of Macroetch Testing and Inspection of Steel Forgings (A 317 – 52 T)
Spec. for Medium-Carbon Steel Joint Bars (A 4 – 49 T)
Spec. for Carbon Steel Forgings for Locomotives and Cars (A 236 – 52 T)
Spec. for Alloy-Steel Forgings for Locomotives and Cars (A 238 – 49 T)
Spec. for Carbon Steel Blooms, Billets, and Slabs for Forgings (A 273 – 52 T)
Spec. for Alloy-Steel Blooms, Billets, and Slabs for Forgings (A 274 – 52 T)
Spec. for Carbon and Alloy-Steel Forgings for Pinions for Reduction Gears (A 291 – 52 T)
Spec. for Carbon and Alloy-Steel Forgings for Turbine Generator Rotors and Shafts (A 292 – 52 T)
Spec. for Carbon and Alloy-Steel Forgings for Turbine Bucket Wheels (A 294 – 52 T)

Adopted as Standard, Revisions in:

Spec. for High-Carbon Steel Joint Bars (A 5 – 53)
Spec. for Multiple-Wear Wrought Steel Wheels (A 57 – 48)
Spec. for Black and Hot-Dipped Zinc-Coated (Galvanized) Welded and Seamless Steel Pipe for Ordinary Uses (A 120 – 47)
Spec. for Electric-Fusion (Arc)-Welded Steel Plate Pipe (Sizes 16 in. and Over) (A 134 – 53)
Spec. for Electric-Fusion (Arc)-Welded Steel Pipe (Sizes 4 in. and Over) (A 139 – 53)
Spec. for One-Wear Wrought Steel Wheels (A 186 – 46)
Spec. for Spiral-Welded Steel or Iron Pipe (A 211 – 44)
Spec. for Welded and Seamless Steel Pipe Piles (A 252 – 46)
Spec. for Seamless and Welded Ferritic Stainless Steel Tubing for General Service (A 268 – 53) (Jointly with Committee A-10)
Spec. for Seamless and Welded Austenitic Stainless Steel Tubing (A 269 – 52) (Jointly with Committee A-10)
Spec. for Seamless and Welded Austenitic Stainless Steel Sanitary Tubing (A 270 – 50) (Jointly with Committee A-10)
Spec. for Seamless Austenitic Chromium-Nickel Steel Still Tubes for Refinery Service (A 271 – 53)
Spec. for Heat-Treated Carbon-Steel Bolting Material (A 261 – 47)

Tentative Withdrawn:

Spec. for Rolled Carbon-Steel Locomotive Frames (A 287 – 46 T)

The committee withdrew from the report as preprinted recommendations for adoption as standard of Tentative Spec. for Boiler and Firebox Steel for Locomotives (A 30 – 52a T), and Tentative Spec. for Carbon and Alloy Steel Forgings for Turbine Rotors and Shafts (A 293 – 52 T).

Committee B-3 on Corrosion of Non-Ferrous Metals and Alloys:

Report presented by K. G. Compton, chairman, and the following actions taken:

Accepted as Tentative:

Method of Acetic Acid-Salt Spray (Fog) Testing (B 287 – 54 T)

Accepted as Tentative, Revisions in:

Method for Salt Spray (Fog) Testing (B 117 - 49 T)

Committee B-6 on Die-Cast Metals and Alloys:

Report presented by W. Babington, chairman, and the following action taken:

Accepted as Tentative, Revisions in:

Spec. for Aluminum-Base Alloy Die Castings (B 85 - 52 T)

Committee E-7 on Non-Destructive Testing:

Report presented in the absence of the chairman by J. W. Caum, and accepted as a report of progress.

Advisory Committee on Corrosion:

Report presented by F. L. LaQue, chairman, and accepted as a report of progress.

TWENTY-SIXTH SESSION—MARBURG LECTURE, DUDLEY MEDAL, AND AWARDS

WEDNESDAY, JUNE 16, 4:30 P.M.

SESSION CHAIRMAN: PRESIDENT L. C. BEARD, JR.

Edgar Marburg Lecture:

President Beard opened the session by giving a brief statement of the purpose of the lecture. Harold F. Dodge, Quality Results Engineer and Member of the Technical Staff, Bell Telephone Laboratories, Inc., was then introduced as the 28th Edgar Marburg Lecturer. In his lecture on "Interpretation of Scientific and Engineering Data," Mr. Dodge discussed the role played by sampling and quality control techniques. He gave particular attention to the application of some of the simpler statistical methods used in the interpretation of data obtained in development, production, and inspection activities. In industry, the development and production of materials and manufactured products involves at every turn the collection, analysis, and interpretation of quantitative data. Most engineering data can advantageously be regarded as a sample to tell something about a larger whole or about the behavior of the cause system or process that gave rise to the data.

President Beard expressed appreciation to Dr. Dodge for his very interesting lecture on a most important subject and presented to him on behalf of the Society the Edgar Marburg Lecture Certificate.

Charles B. Dudley Medal:

The Twenty-sixth Award of the Charles B. Dudley Medal was made to C. E. Work, Assistant Professor, and T. J. Dolan, Research Professor, University of Illinois, Urbana, Ill., for their paper on "The Influence of Strain-Rate and Temperature on the Strength and Ductility of Mild Steel in Torsion," presented at the 1953 Annual Meeting and published in the 1953 *Proceedings*.

Richard L. Templin Award:

The Ninth Richard L. Templin Award was made to Messrs. E. T. Wessel and R. D. Olleman, Metallurgical and Ceramic Department, Westinghouse Electric Corp., East Pittsburgh, Pa., for their paper on "Apparatus for Tension Testing at Subatmospheric Temperatures," published in the ASTM BULLETIN, No. 187, January, 1953.

Sam Tour Award:

The Fifth Sam Tour Award was made to John T. Richards, Chief Engineer, Penn Precision Co., Inc., Reading, Pa., for his paper on "The Corrosion of Beryllium Copper Strip in Sea Water and Marine Atmospheres," presented at the 1953 Annual Meeting and published in the 1953 *Proceedings*.

TWENTY-SEVENTH SESSION—SYMPOSIUM ON EFFECT OF CYCLIC HEATING AND STRESSING ON METALS AT ELEVATED TEMPERATURES[13]

THURSDAY, JUNE 17, 9:15 A.M.

SESSION CHAIRMAN: D. N. FREY

What We Need to Know About Creep—John E. Dorn and Lawrence A. Shepard, presented from manuscript by Mr. Shepard.

The Problem of Thermal Stress Fatigue in Austenitic Steels at Elevated Temperatures—L. F. Coffin, Jr., presented by the author.

The Effect of Temperature Cycling on the Rupture Strength of Some High-Temperature Alloys—J. Miller, presented by the author.

Experiments on the Effects of Temperature and Load Changes on Creep-Rupture of Steels—G. V. Smith and E. G. Houston, presented from manuscript by Mr. Smith.

(*Symposium Continued in Twenty-eighth Session*)

TWENTY-EIGHTH SESSION—SYMPOSIUM ON EFFECT OF CYCLIC HEATING AND STRESSING ON METALS AT ELEVATED TEMPERATURES[13]

(*Symposium Continued from Twenty-Seventh Session*)

THURSDAY, JUNE 17, 2:00 P.M.

SESSION CHAIRMAN: F. B. FOLEY

Effects of Cyclic Overloads on the Creep Rates and Rupture Life of Inconel at 1700 and 1800 F—R. H. Caughey and W. B. Hoyt, presented from manuscript by Mr. Hoyt.

The Creep-Rupture Properties of Aircraft Sheet Alloys Subjected to Intermittent Load and Temperature—G. J. Guarnieri, presented from manuscript by the author.

Constant and Cyclic-Stress Creep Tests of Several Sheet Materials—Ward F. Simmons and Howard C. Cross, presented by Mr. Simmons.

The Effect of Composition on the Scaling of Fe-Cr-Ni Alloys Subjected to Cyclic Temperature Conditions—H. E. Eiselstein and E. N. Skinner, presented from manuscript by Mr. Skinner.

Summary—D. N. Frey.

TWENTY-NINTH SESSION—REPORT SESSION

THURSDAY, JUNE 17, 4:30 P.M.

SESSION CHAIRMAN: VICE-PRESIDENT C. H. FELLOWS

Committee A-10 on Iron-Chromium, Iron-Chromium-Nickel, and Related Alloys:

Report presented by Jerome Strauss, chairman, and the following actions taken:

Accepted as Tentative:

Rec. Practice for Descaling and Cleaning Stainless Steel Surfaces (A 380 - 54 T)

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[13] Issued as separate technical publication *ASTM STP No. 165.*

Accepted as Tentative, Revision in:

Spec. for Seamless and Welded Austenitic Stainless Steel Pipe (A 312 - 51 T) (Jointly with Committee A-1)

Adopted as Standard:

Spec. for Hot-Rolled and Cold-Finished Corrosion-Resisting Steel Bars (A 276 - 49 T)

Adopted as Standard, Revisions in:

Spec. for Corrosion-Resisting Chromium-Nickel Steel Plate, Sheet, and Strip (A 167 - 44)
Spec. for Corrosion-Resisting Chromium Steel Plate, Sheet, and Strip (A 176 - 49)
Spec. for High-Strength Corrosion-Resisting Chromium-Nickel Steel Sheet and Strip (A 177 - 44)
Spec. for Corrosion-Resisting Chromium and Chromium-Nickel Steel Plate, Sheet, and Strip for Fusion-Welded Unfired Pressure Vessels (A 240 - 49)
Spec. for Seamless and Welded Ferritic Stainless Steel Tubing for General Service (A 268 - 53) (Jointly with Committee A-1)
Spec. for Seamless and Welded Austenitic Stainless Steel Tubing for General Service (A 269 - 52) (Jointly with Committee A-1)
Spec. for Seamless and Welded Austenitic Stainless Steel Sanitary Tubing (A 270 - 50) (Jointly with Committee A-1)
Spec. for Seamless Austenitic Chromium-Nickel Steel Still Tubes for Refinery Service (A 271 - 53) (Jointly with Committee A-1)

Committee D-11 on Rubber and Rubber-like Materials:

Report presented by Arthur Carpenter, secretary, and the following actions taken:

Accepted as Tentative:

Spec. for Sheet Rubber Packing (D 1330 - 54 T)
Methods for Evaluating Low-Temperature Characteristics of Rubber and Rubber-Like Materials by a Temperature-Retraction Procedure (TR Test) (D 1329 - 54 T)

Accepted as Tentative, Revisions in:

Methods of Sample Preparation for Physical Testing of Rubber Products (D 15 - 52 T)
Methods for Chemical Analysis of Rubber Products (D 297 - 50 T)
Methods of Testing Automotive Air Brake and Vacuum Brake Hose (D 622 - 48 T)
Spec. for Rubber and Synthetic Rubber Compounds for Automotive and Aeronautical Applications (D 735 - 52a T)
Test for Low-Temperature Brittleness of Rubber and Rubber-Like Materials (D 736 - 46 T)
Method of Measuring Low-Temperature Stiffening of Rubber and Rubber-Like Materials by the Gehman Torsional Apparatus (D 1053 - 52 T)
Spec. and Methods of Test for Latex Foam Rubbers (D 1055 - 53 T)
Spec. and Methods of Test for Sponge and Expanded Cellular Rubber Products (D 1056 - 53 T)
Spec. and Methods of Test for Concentrated, Ammonia Preserved, Creamed and Centrifuged Natural Rubber Latex (D 1076 - 52 T)
Spec. for Non-Metallic Gasket Materials for General Automotive and Aeronautical Purposes (D 1170 - 51 T)
Methods of Testing Adhesives for Brake Lining and Other Friction Materials (D 1205 - 52 T)

Adopted as Standard, Revisions in:

Test for Tear Resistance of Vulcanized Rubber (D 624 - 48)

Committee D-12 on Soaps and Other Detergents:

Report presented in the absence of the chairman by P. J. Smith, and the following actions taken:

Accepted as Tentative:

Test for Surface and Interfacial Tension of Solutions of Surface-Active Agents (D 1331 - 54 T)

Accepted as Tentative, Revisions in:

Test for pH of Aqueous Solutions of Soaps and Detergents (D 1172 - 51 T)

Adopted as Standard, Revisions in:

Methods of Sampling and Chemical Analysis of Soaps and Soap Products (D 460 - 46)
Methods of Sampling and Chemical Analysis of Alkaline Detergents (D 501 - 49)
Def. of Terms Relating to Soaps and Other Detergents (D 459 - 52)

The revisions for immediate adoption set forth in the preprinted report with respect to Specifications D 928 - 52 should have been listed as an editorial change since they represent the correction of a typographical error that had occurred in a recent printing of the specifications.

Committee D-13 on Textile Materials:

Report presented by S. J. Hayes, vice-chairman, and the following actions taken:

Accepted as Tentative:

Test for Determination of Build-Up and Spread of Glass Yarn as Wrap (Serving) or Braid Over Electrical Conductors (D 1332 – 54 T)
Methods of Testing Elastic Fabrics (D 1333 – 54 T)
Test for Tuft Bind of Pile Floor Coverings (D 1335 – 54 T)
Test for Yarn Distortion in Woven Fabrics (D 1336 – 54 T)
Test for Wool Content of Raw Wool (Commercial Scale) (D 1334 – 54 T)
Test for "Fineness" of Cotton Fibers by Resistance to Air Flow (Micronaire Method) (D 1448 – 53 T)
Test for Length of Cotton Fibers by Fibrograph (D 1447 – 54 T)

Accepted as Tentative, Revisions in:

General Methods of Testing Cotton Fibers (D 414 – 53 T)
Test for Total Wool Fiber Present in Wool in the Grease (D 584 – 53 T)
Methods of Core Sampling of Wool in Packages for Determination of Percentage of Total Wool Fiber Present (D 1060 – 53 T)
Methods of Testing and Tolerances for Rayon Tire Cord (D 885 – 53 T)
Methods of Testing and Tolerances for Cotton Yarns (D 180 – 52 T)
Rec. Practice for Interlaboratory Testing of Textile Materials (D 990 – 52 T)
Test for Snag Resistance of Hosiery (D 1115 – 50 T)
Def. of Terms Relating to Textile Materials (D 123 – 53 T), with an editorial correction in the definition of "Slide Fasteners" to change the last word "scoops" to read "strip."
Spec. for Woven Asbestos Cloth (D 677 – 50)
Methods of Testing and Tolerances for Certain Wool and Part Wool Fabrics (D 462 – 53)
Test for Maximum Residual Shrinkage of Silk and Rayon, and Acetate Woven Fabrics (D 416 – 39)
Test for Vegetable Matter in Scoured Wool (D 1113 – 52)

Adopted as Standard:

Def. of Terms Relating to Textile Materials (D 123 – 53 T): Definitions for 10 terms as set forth in the preprinted report, now appearing in Tentative D 123 – 53 T, were recommended by the committee for adoption as standard. The following 8 definitions were withdrawn from the report as preprinted and will be continued as tentative: Bleaching, Compliance, Lea, Lea Skein, Top, Woolen Spun, Worsted Spun, Yarn Unevenness.
Methods of Quantitative Analysis of Textiles (D 629 – 46 T)
Test for Small Amounts of Copper and Manganese in Textiles (D 377 – 52 T)
Test for Colorfastness to Light of Textiles (D 506 – 52 T)
Test for Resistance of Textile Fabrics and Yarns to Insect Pests (D 582 – 49 T)
Test for Water Resistance of Textile Fabrics (D 583 – 52 T)
Test for Evaluating Compounds Designed to Increase Resistance of Fabrics and Yarns to Insect Pests (D 627 – 49 T)
Test for Resistance of Textile Materials to Microorganisms (D 684 – 53 T)
Test for Evaluating Treated Textiles for Permanence of Resistance to Microorganisms (D 862 – 45 T)
Test for Shrinkage in Laundering of Knit Cotton Fabrics (D 1231 – 52 T)
Test for Shrinkage in Laundering of Knit Rayon Fabrics (D 1232 – 52 T)
Methods of Sampling Cotton Fibers for Testing (D 1441 – 52 T)
Test for Fiber Weight per Unit Length and Maturity of Cotton Fibers (Array Method) (D 1442 – 52 T)
Test for Sampling and Testing Staple Length of Wool in the Grease (D 1234 – 52 T)
Spec. and Methods of Test for Asbestos Yarns (D 299 – 52 T)
Spec. and Methods of Test for Asbestos Lap (D 1061 – 52 T)

Accepted for Publication as Information Only:

Differential Dye Test for Predicting Dyeing Behavior of Cotton.

Committee D-17 on Naval Stores:

Report presented by V. E. Grotlisch, chairman, and the following actions taken:

Adopted as Standard:

Test for Rosin Acids in Fatty Acids (D 1240 – 52 T)

Committee E-2 on Emission Spectroscopy:

Report presented by B. F. Scribner, chairman, and accepted as a report of progress.

Committee E-10 on Radioactive Isotopes:

Report presented by D. M. McCutcheon, chairman, and accepted as a report of progress.

Committee E-13 on Absorption Spectroscopy:

Report presented in the absence of the chairman by P. J. Smith, and accepted as a report of progress.

Committee E-14 on Mass Spectrometry:

Report presented in the absence of the chairman by P. J. Smith, and accepted as a report of progress.

THIRTIETH SESSION—CREEP

THURSDAY, JUNE 17, 8:00 P.M.

SESSION CHAIRMAN: G. R. GOHN

The Creep Characteristics of Copper-Nickel Alloys at 300, 400, and 500 F—J. H. Port and A. I. Blank, presented by Mr. Port.

Creep Properties of Annealed Unalloyed Zirconium—M. J. Manjoine and W. L. Mudge, Jr., presented by Mr. Manjoine.

Tensile and Creep Properties at Elevated Temperatures of Some Magnesium-Base Wrought Alloys—Hugh Baker, presented from manuscript by the author.

Tensile and Creep Properties at Elevated Temperatures of Some Magnesium-Base Sand Casting Alloys—K. E. Nelson, presented from manuscript by the author.

THIRTY-FIRST SESSION—CONCRETE, CEMENTITIOUS MATERIALS

THURSDAY, JUNE 17, 8:00 P.M.

SESSION CHAIRMAN: A. ALLAN BATES

Investigations Relating to the Use of Fly Ash as a Pozzolan and as an Admixture in Portland-Cement Concrete—L. John Minnick. (Presented by title.)

Some Observations on the Mechanics of Alkali-Aggregate Reaction—L. S. Brown, presented from manuscript by the author.[14]

Statistical Relation Between Cylinder, Modified Cube, and Beam Strength of Concrete—Clyde E. Kesler, presented by the author.

A Rapid Accelerated Test for Cement-Aggregate Reaction—C. H. Scholer and G. M. Smith, presented by Mr. Smith.

Cracking in Masonry Caused by Moisture Expansion of Structural Clay Tile—J. W. McBurney, presented by the author.

Some Volume Changes in Mortar and Concrete—F. O. Anderegg and J. A. Anderegg, presented from manuscript by Mr. J. A. Anderegg.[14]

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[14] To be published in the ASTM BULLETIN.

THIRTY-SECOND SESSION—SYMPOSIUM ON METHODS OF TESTING BUILDING CONSTRUCTIONS[15]

THURSDAY, JUNE 17, 8:00 P.M.

SESSION CHAIRMAN: W. T. SAVAGE

Introduction—W. T. Savage.

Why Test Building Constructions?—H. L. Whittemore, presented from manuscript by Mr. J. W. McBurney.

Structural Performance Requirements in Housing Codes—Lyman W. Wood, presented from manuscript by the author.

Transverse Tests of Masonry Walls—C. B. Monk, Jr., presented from manuscript by the author.

Fire Tests of Building Structures and Materials and Their Utilization in Building Code Requirements—A. J. Steiner, presented from manuscript by the author.

(Symposium Continued in Thirty-third Session)

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[15] Issued as separate technical publication *ASTM STP No. 166.*

THIRTY-THIRD SESSION—SYMPOSIUM ON METHODS OF TESTING BUILDING CONSTRUCTIONS[15]

(*Symposium Continued from Thirty-second Session*)

FRIDAY, JUNE 18, 9:15 A.M.

SESSION CHAIRMAN: LYMAN W. WOOD

History and Bibliography of Wood Diaphragm Tests—A. C. Horner, presented from manuscript by the author.

Glued and Nailed Roof Trusses for House Construction—R. F. Luxford, presented from manuscript by the author.

Lateral Tests on Full-Scale Lumber- and Plywood-Sheathed Roof Diaphragms—J. R. Stillinger, presented from manuscript by Mr. J. W. Johnson.

Summary—J. A. Liska.

Committee C-7 on Lime:

Report presented by E. E. Eakins, vice-chairman, and accepted as a report of progress.

Committee C-20 on Acoustical Materials:

Report presented by H. J. Sabine, secretary, and accepted as a report of progress.

Committee D-7 on Wood:

Report presented in the absence of the chairman by L. C. Gilbert, and the following actions taken:

Accepted as Tentative:

Spec. for Modified Woods (D 1324 - 54 T)

Spec. for Ammoniacal Copper Arsenite (D 1325 - 54 T)

Methods of Chemical Analysis of Ammoniacal Copper Arsenite (D 1326 - 54 T)

Accepted as Tentative, Revisions in:

Spec. for Round Timber Piles (D 25 - 53 T)

Committee E-6 on Methods of Testing Building Constructions:

Report presented by J. A. Liska, chairman, and the following action taken:

Adopted as Standard:

Methods of Conducting Strength Tests of Panels for Building Construction (E 72 - 51 T)

THIRTY-FOURTH SESSION—PLASTICS

FRIDAY, JUNE 18, 9:15 A.M.

SESSION CHAIRMAN: H. K. NASON

Papers:

Measuring Viscosity of Thermosetting Resins by Parallel Plate Plastometry—Donald I. Marshall, presented by the author.[16]

Effect of Crystallinity, and Crazing, Aging, and Residual Stress, on Creep of Kel-F, Canvas Laminate, and Geon, Respectively—W. N. Findley, presented from manuscript by the author.

Creep-Time Relations for Nylon in Tension, Compression, Bending, and Torsion—Joseph Marin, A. C. Webber, and G. Weissmann, presented by Mr. Weissmann.

Time-Temperature Relationship for Rupture Stresses in Reinforced Plastics—S. Goldfein, presented by the author.

Committee D-20 on Plastics:

Report presented by R. K. Witt, chairman, and the following actions taken:

Accepted as Tentative, Revisions in:

Spec. for Phenolic Molding Compounds (D 700 - 52 T) (Jointly with Committee D-9)

Spec. for Enclosures and Servicing Units for Tests Above and Below Room Temperature (D 1197 - 52 T) (Jointly with Committee D-9)

Test for Impact Resistance of Plastics and Electrical Insulating Materials (D 256 - 47 T)

Spec. for Molds for Test Specimens of Plastic Molding Materials (D 647 - 51 T)

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[16] Published in the ASTM BULLETIN, No. 204, February, 1955, p. 40 (TP 42).

Test for Brittleness Temperature of Plastics and Elastomers by Impact (D 746 - 52 T)
Test for Resistance to Abrasion (Optical Effects) of Transparent Plastics (D 1044 - 49 T)
Def. of Terms Relating to Plastics (D 883 - 53 T), with definition of "Gel" omitted from report as preprinted and definition of "Creep" modified editorially
Test for Measuring the Molding Index of Thermosetting Molding Powder (D 731 - 50)
Descriptive Nomenclature of Objects Made from Plastics (D 675 - 45), with definitions of the terms "Frosting," "Gloss," "Haze, Internal," "Haze, Surface," "Let-Go," and "Lubricant-Bloom" withdrawn from report as preprinted.

Adopted as Standard:

Spec. for Primary Octyl Phthalate Ester Plasticizers (D 1249 - 52 T)
Test for Compressive Properties of Rigid Plastics (D 695 - 52 T)
Test for Bearing Strength of Plastics (D 953 - 48 T)
Test for Apparent Density and Bulk Factor of Granular Thermoplastic Molding Powder (D 1182 - 51 T)
Test for Measurement of Changes in Linear Dimensions of Nonrigid Thermoplastic Sheeting or Film (D 1204 - 52 T)
Test for Specific Viscosity of Vinyl Chloride Polymers (D 1243 - 52 T)

Adopted as Standard, Revisions in:

Test for Diffusion of Light by Plastics (D 636 - 43)
Test for Luminous Reflectance, Transmittance, and Color of Materials (D 791 - 50)
Method of Conditioning Plastics and Electrical Insulating Materials for Testing (D 618 - 53) (Jointly with Committee D-9)

Tentatives Withdrawn:

Test for Water Vapor Permeability of Plastic Sheets (D 697 - 42 T)
Test for Weight Loss of Plastics on Heating (D 948 - 47 T)
Rec. Practice for Transfer Molding of Specimens of Phenolic Materials (D 1046 - 49 T)

The committee withdrew from the report as preprinted recommendations for adoption as standard of Tentative Method of Test for Repeated Flexural Stress (Fatigue) of Plastics (D 671 - 52 T); Tentative Method of Test for Volatile Loss from Plastic Materials (D 1203 - 52 T); and Tentative Method of Test for Measuring Flow Rates of Thermoplastics by Extrusion Plastometer (D 1238 - 52 T).

Committee D-14 on Adhesives:

Report presented in the absence of the chairman by S. F. Etris, and the following actions taken:

Accepted as Tentative:

Test for Storage Life of Adhesives by Consistency and Bond Strength (D 1337 - 54 T)
Test for Working Life of Liquid or Paste Adhesives by Consistency and Bond Strength (D 1338 - 54 T)

Adopted as Standard:

Spec. for Impact Strength of Adhesives (D 950 - 52 T)

Accepted for Publication as Information Only:

Method for Testing Bonded Specimens as Cantilever Beams Under Repeated Constant Deflection
Test for Susceptibility of Dry Adhesive Films to Attack by Roaches
Test for Susceptibility of Dry Adhesive Films to Attack by Laboratory Rats

Committee D-23 on Cellulose and Cellulose Derivatives:

Report presented in the absence of the chairman by S. F. Etris, and the following actions taken:

Accepted as Tentative:

Test for Viscosities of Cellulose Derivatives by the Ball-Drop Method (D 1343 - 54 T)

Accepted as Tentative, Revisions in:

Methods of Testing Cellulose Acetate (D 871 - 48)

THIRTY-FIFTH SESSION—IMPACT

FRIDAY, JUNE 18, 9:15 A.M.

SESSION CHAIRMAN: E. F. LUNDEEN

Poisson Effect in the Charpy Test—Carl E. Hartbower, presented by the author.
Effect of Microstructure on the Elevated Temperature Strength of Alloy Steel—J. J. Heger, J. M. Hodge, and P. W. Marshall, presented from manuscript by Mr. Heger.

Short-Time Tension and Creep-Rupture Properties of Hardened 1040, 4340, and Ni-Cr-Mo-V Steels Up to 1000 F—G. V. Smith and W. B. Seens, presented by Mr. Smith.

Effect of Specimen Size on Notched Bar Impact Properties of Quenched-and-Tempered Steels--Harry Schwartzbart and J. P. Sheehan, presented by Mr. Sheehan.

Notch Bar Tests of High-Strength Steel—Richard H. Raring and J. A. Rinebolt, presented by Mr. Raring.

THIRTY-SIXTH SESSION—REPORT SESSION

FRIDAY, JUNE 18, 11:30 A.M.

SESSION CHAIRMAN: PRESIDENT L. C. BEARD, JR.

Committee A-3 on Cast Iron:

Report presented by J. S. Vanick, chairman, and the following action taken:

Accepted as Tentative:

Spec. for Cast Iron Pressure Pipe (A 377 - 54 T)

Adopted as Standard:

Methods of Impact Testing of Cast Iron (A 327 - 50 T)

Standard Withdrawn:

Spec. for Cast Iron Pit-Cast Pipe for Water or Other Liquids (A 44 - 41)

Committee A-7 on Malleable-Iron Castings:

Report presented by W. A. Kennedy, chairman, and the following actions taken:

Adopted as Standard:

Spec. for Malleable Iron Flanges, Pipe Fittings, and Valve Parts for Railroad, Marine, and Other Heavy Duty Service (A 338 - 51 T)

Committee C-9 on Concrete and Concrete Aggregates:

Report presented by L. W. Teller, chairman, and the following actions taken:

Accepted as Tentative:

Test for Volume Change of Concrete Products (C 341 - 54 T)

Test for Potential Volume Change of Cement-Aggregate Combinations (C 342 - 54 T)

Accepted as Tentative, Revisions in:

Test for Volume Change of Cement Mortar and Concrete (C 157 - 52 T)

Test for Potential Reactivity of Aggregates (Chemical Method) (C 289 - 52 T)

Test for Flexural Strength of Concrete (Using Simple Beam with Center-Point Loading) (C 293 - 52 T)

Descriptive Nomenclature of Constituents of Natural Mineral Aggregates (C 294 - 52 T)

Def. of Terms Relating to Concrete and Concrete Aggregates (C 125 - 48)

Adopted as Standard:

Method of Making and Curing Concrete Compression and Flexure Test Specimens in the Laboratory (C 192 - 52 T)

Method of Sampling Fresh Concrete (C 172 - 52 T)

Test for Air Content of Freshly Mixed Concrete by the Pressure Method (C 231 - 52 T)

Method of Testing Air-Entraining Admixtures for Concrete (C 233 - 52 T)

Test for Comparing Concretes on the Basis of the Bond Developed with Reinforcing Steel (C 234 - 49 T)

Test for Soft Particles in Coarse Aggregates (C 235 - 49 T) (Jointly with Committee D-4)

Rec. Practice for Petrographic Examination of Aggregates for Concrete (C 295 - 52 T)

Spec. for Air-Entraining Admixtures for Concrete (C 260 - 52 T)

Adopted as Standard, Revisions in:

Test for Cement Content of Hardened Portland-Cement Concrete (C 85 - 42)

Spec. for Ready-Mixed Concrete (C 94 - 48)

Standard Withdrawn:

Spec. for Lightweight Aggregates for Concrete (C 130 - 42)

Committee C-12 on Mortars for Unit Masonry:

Report presented by J. M. Hardesty, chairman, and the following action taken:

Accepted as Tentative, Revision in:

Spec. for Mortar for Unit Masonry (C 270 - 52 T)

Committee D-2 on Petroleum Products and Lubricants:

Report presented by W. T. Gunn, secretary, and the following actions taken:

Accepted as Tentative:

Test for Tensile Strength of Paraffin Wax (D 1320 - 54 T)
Test for Needle Penetration of Petroleum Waxes (D 1321 - 54 T)
Test for Smoke Point of Jet Fuels (D 1322 - 54 T)
Test for Mercaptan Sulfur in Jet Fuels (Amperometric Method) (D 1323 - 54 T)
Test for Hydrocarbon Types in Liquid Petroleum Products by Fluorescent-Indicator Adsorption (FIA) Method (D 1319 - 54 T)
Test for Sodium in Residual Fuels by Flame Photometer (D 1318 - 54 T)
Test for Chlorine in Lubricating Oils (Sodium Alcoholate Volumetric Method) (D 1317 - 54 T)

Accepted as Tentative, Revisions in:

Test for Free and Corrosive Sulfur in Petroleum Products (Copper Strip Test) (D 130 - 50 T)
Test for Existent Gum in Fuels by Jet Evaporation (D 381 - 52 T)
Test for Neutralization Value (Acid and Base Numbers) by Color-Indicator Titration (D 974 - 53 T)
Test for Determination of Purity from Freezing Points (D 1016 - 52 T)
Method of Measuring the Temperature of Petroleum and Petroleum Products (D 1086 - 52 T)
Test for Phosphorus in Lubricating Oils, Lubricating Oil Additives, and Their Concentrates (D 1091 - 50 T)
Test for Distillation of Crude Petroleum (D 285 - 52)

Adopted as Standard:

Test for API Gravity of Petroleum and Its Products (Hydrometer Method) (D 287 - 53 T)
Test for Rust-Preventing Characteristics of Steam-Turbine Oil in the Presence of Water (D 665 - 53 T)
Test for Oxidation Characteristics of Inhibited Steam-Turbine Oils (D 943 - 53 T)
Test for Analysis of 60 Octane Number Isooctane-Normal Heptane ASTM Knock Test Reference Fuel Blends by Infrared Spectrophotometry (D 1095 - 50 T)
Test for 1,3-Butadiene in C_4 Hydrocarbon Mixtures by Ultraviolet Spectrophotometry (D 1096 - 50 T)
Test for Total Inhibitor Content (p-Tertiary-Butylcatechol) of Butadiene (D 1157 - 51 T)
Def. and Spec. for Farm Tractor Fuels (D 1215 - 52 T)
Test for Density and Specific Gravity of Liquids by Bingham Pycnometer (D 1217 - 52 T)
Test for Specific Gravity of Petroleum and Its Products (Hydrometer Method) (D 1298 - 53 T)

Adopted as Standard, Revisions in:

Test for Distillation of Gasoline, Naphtha, Kerosine, and Similar Petroleum Products (D 86 - 53)
Test for Distillation of Gas Oil and Similar Distillate Fuel Oils (D 158 - 53)
Test for Distillation of Natural Gasoline (D 216 - 53)
Test for Neutralization Value (Acid and Base Numbers) by Potentiometric Titration (D 664 - 52)
Test for Saponification Number of Petroleum Products by Potentiometric Titration (D 939 - 52)

Accepted for Publication as Information Only:

Test for Filterability of Jet Fuel
Test for Mercaptan Sulfur in Jet Fuels (Potentiometric Titration Method)
Test for Individual Hydrocarbons in a C_4 Fraction by Infrared Spectrophotometric Method
Test for Emulsion Characteristics of Steam-Turbine Oils
Revision of Tentative Method of Sampling Petroleum and Petroleum Products (D 270 - 53 T)
Revision of Tentative Method of Measuring the Temperature of Petroleum and Petroleum Products (D 1086 - 52 T)
Revision of Tentative Method of Test for Reduced Pressure Distillation of Petroleum Products (D 1160 - 52 T)

The committee withdrew from the report as preprinted recommendations for (1) revision of Tentative Rec. Practice for Volume Calculations and Corrections in Measurements of Petroleum and Petroleum Products (D 1087 - 52 T); and (2) publication as information of the Test for Water in Petroleum and Bituminous Products.

Committee D-8 on Bituminous Waterproofing and Roofing Materials:

Report presented by H. R. Snoke, chairman, and the following actions taken:

Accepted as Tentative:

Spec. for Woven Burlap Fabrics Saturated with Bituminous Substances for Use in Waterproofing (D 1327 – 54 T)
Test for Staining Properties of Asphalts (Modified Pressure Method) (D 1328 – 54 T)

Accepted as Tentative, Revisions in:

Methods of Testing Asphalt Roll Roofing, Cap Sheets, and Shingles (D 228 – 48 T)
Spec. for Asphalt Roofing Surfaced with Mineral Granules (D 249 – 50 T)
Spec. for Asphalt Shingles Surfaced with Mineral Granules (D 225 – 51)
Spec. for Asphalt-Saturated Roofing Felt for Use in Waterproofing and in Constructing Built-Up Roofs (D 226 – 47)
Spec. for Coal Tar Saturated Roofing Felt for Use in Waterproofing and in Constructing Built-Up Roofs (D 227 – 47)
Spec. for Asphalt-Saturated Asbestos Felts for Use in Waterproofing and in Constructing Built-Up Roofs (D 250 – 47)

Adopted as Standard:

Def. of Terms Relating to Bituminous Waterproofing and Roofing Materials (D 1079 – 52 T)

Adopted as Standard, Revisions in:

Spec. for Asphalt Shingles Surfaced with Mineral Granules (D 225 – 51)
Spec. for Asphalt Roofing Surfaced with Powdered Talc or Mica (D 224 – 52)
Spec. for Asphalt Siding Surfaced with Mineral Granules (D 699 – 51)

Committee D-15 on Engine Antifreezes:

Report presented in the absence of the chairman by P. J. Smith, and the following actions taken:

Adopted as Standard:

Test for Reserve Alkalinity of Concentrated Engine Antifreezes (D 1121 – 50 T)
Test for Water in Concentrated Engine Antifreezes by the Iodine Reagent Method (D 1123 – 50 T)
Method for Sampling and Preparing Aqueous Solutions of Engine Antifreeze for Testing Purposes (D 1176 – 52 T)
Test for Freezing Point of Aqueous Engine Antifreeze Solution (D 1177 – 52 T)

Committee D-19 on Industrial Water:

Report presented in the absence of the chairman by M. D. Huber, and the following actions taken:

Accepted as Tentative:

Test for Sulfite Ion in Industrial Water (D 1339 – 54 T)
Method for Determination of Thickness of Internal Deposits on Tubular Heat Exchange Surfaces (D 1341 – 54 T)
Test for Oily Matter in Industrial Water (D 1340 – 54 T)

Accepted as Tentative, Revisions in:

Test for Total Carbon Dioxide and Calculation of the Carbonate and Bicarbonate Ions in Industrial Water (D 513 – 50 T)
Test for Suspended and Dissolved Solids in Industrial Water (D 1069 – 49 T)
Methods of Sampling Industrial Water (D 510 – 52 T)
Methods of Sampling Steam (D 1066 – 49 T)
Test for Chloroform-Extractable Matter in Industrial Water (D 1178 – 51 T)
Method of Reporting Results of Analysis of Industrial Water (D 596 – 49)

Adopted as Standard:

Method of Sampling Water from Boilers (D 860 – 51 T)

Adopted as Standard, Revisions in:

Def. of Terms Relating to Industrial Water (D 1129 – 53)

Accepted for Publication as Information Only:

Test for Hardness of Industrial Water
Test for Hydroxide Ion in Industrial Water
Test for Nitrate Ion in Industrial Water
Test for Sulfite Ion in Industrial Water
Test for the Evaluation of the Acute Toxicity of Industrial Waste to Fresh Water Fishes

Announcement was made of the first Max Hecht Award, which was made at the meeting of Committee D-19. This award is presented in recognition of outstanding service to Committee D-19 on Industrial Water in the advancement of its objective—the study of water as an engineering material. The award was established by the committee in 1954 in honor of its first chairman, Max Hecht, who was the recipient of the first award.

Committee D-21 on Wax Polishes and Related Material:

Report presented in the absence of the chairman by S. F. Etris, and the following action taken:

Accepted as Tentative:

Test for Paraffin-Type Hydrocarbons in Carnauba Wax (D 1342 - 54 T)

"PLAIN TALK"

ANNUAL ADDRESS BY THE PRESIDENT

L. C. BEARD, JR.[1]

JUNE 15, 1954

OVER the past year three principles have governed the actions of your Staff Officers and Directors:

- alert progressiveness in technical matters,
- democracy in operation, and
- considered long-range financial planning.

I will not dwell on these matters since they are referred to directly or by inference in the 1954 Report of the Board of Directors and reference can be made to the report itself by those wishing more details.

Instead, I shall take advantage of the opportunity afforded each President to make an annual address and discuss an unhealthy trend in science which is giving much concern, and about which we all can, and I hope will, do something.

What I refer to is the breakdown in communications between the various sciences and between science and the public.

I say to you—"La scienza è scienza solamente quando il primo spazzaturaio ti comprende"—and unless you understand Italian and can surmount my mispronunciation, this means nothing to you. If I translate this old proverb—"Science is science only when the first streetcleaner understands you"—you know what I'm talking about and you also have the text of this address. I could call the salad you have just eaten—"Lamellar fibrous cellulose impregnated with chlorophyll and tumbled with a triglyceride-acetic acid emulsion"—frankly, I prefer to call it "green salad with French dressing."

The sciences have become so complex and workers in them have built up their own vocabularies to such an extent that a chemist has difficulty in understanding a physicist; the biologist can't talk to the geologist; none of them can talk plainly to the engineer. Sometimes the engineer can't get his ideas across to management; and few technical people can explain their aims and what they have done, to the public. Now the engineer must put the scientists' fundamental discoveries on the assembly line and ultimately the public must pay for it. This can be done well and quickly only if each has a clear understanding of what the other is talking about.

This breakdown in communications retards invention and stifles the fruits of it. How does this come about? In this way. There are three steps in making an invention: first, there is the recognition of the problem—some human want to be satisfied, some obscure thing to be made clear, or relations between things or events to be organized into a "law."

The second step is fact finding and

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[1] Assistant Director, Socony-Vacuum Laboratories, Socony-Vacuum Oil Co., Inc., New York, N. Y.

data collecting. The prospective inventor must get all the human experience and observation that will assist him in solving his problem. In short, he studies the technical literature. He must stuff his conscious mind to the point of bursting with anything that may be remotely related to the problem to be solved. Now strange as it may seem, he is less likely to get an invention from reading the literature obviously pertinent to his problem. For example, if he wants to make an improved steel, he won't find the answer in the technical literature on steel; because if it were already there, it wouldn't be new and, hence, would not be an invention. Further, a good way to get fired is to publish something before it is patented. We see, then, that ideas gleaned from nonobvious sources are most likely to be new.

All of this means our prospective inventor must be able clearly to understand what he reads. If the literature is gibberish, understood by only a select few, then indeed our prospective inventor has a rough road ahead. I used the word "gibberish" advisedly because it is derived from Geber, a famous Arabian alchemist who was a master of the jargon of his profession.

We will assume now that our prospective inventor has somehow overcome the communication difficulties and has crammed his conscious mind with a wealth of scientific experience. Now all of this finds its way into his subconscious mind and tosses around there like the bits of colored glass in a kaleidoscope. Suddenly the pieces click together into a beautiful pattern and he has an invention, or a solution, or a "law." There is not much that can be done about controlling the operation of the subconscious mind; it works while you sleep, or play, or do most anything except think about the problem to be solved.

There is, however, something we can do about the fact-collecting phase, both to help ourselves and others, that is, ***talk plain.***

I don't want you to think that this important conclusion is original with me. Many great contemporary scientists have written about it.

Vannevar Bush, addressing the Medical Society of the District of Columbia last year, warned that over specialization and the volume of publication are driving groups of scientists to develop their own jargon, unintelligible except to the initiated, heightening the barriers which separate their works from the main stream of progress. He said there were two concrete things that could be done about it. First, scientists could be intelligible. He said they have a moral obligation to express themselves so that they can be quickly understood by those within their profession or closely related professions. Second, those who possess that unique skill should be encouraged to gather, integrate, and interpret the information developed by many workers so that great masses of seemingly confused data become clear, intelligible, and useful to their fellows. Incidentally, the article in *Chemical & Engineering News*[2] from which the above was abstracted was titled—"A Tower of Babel in Science?"

In 1952, Detlev Bronk, who, you will recall, was our guest speaker that year at our Fiftieth Anniversary meeting, told a meeting of the American Association for the Advancement of Science[3] that "universities were doing a grave disservice to the future of American scientists by not giving them an adequate stimulus to develop appreciation and affection for the sharp meaning of the right word."

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[2] Vannevar Bush, "A Tower of Babel in Science?" Abstract of Speech, *Chemical and Engineering News*, Vol. 31, No. 16, April 20, 1953, p. 1621.

[3] Detlev Bronk, Address before American Association for the Advancement of Science, news article in *The Baltimore Sun*, December 30, 1952.

Melba Phillips reporting for a group of scientists in the magazine *Science*[4] said: "In England, France, and Germany, there sprang up in the nineteenth century a tradition of the scientist's obligation to interpret his philosophy and his results to the nonscientific public to which, in the broadest sense, he owed his support. At the present, Albert Einstein is an outstanding exemplar of this tradition, which was notably supported in the past by Faraday, Pasteur, Huxley, and Poincaré, among others. Most American scientists have retreated so far into the remote reaches of specialization that they have largely forgotten their obligation to the public."

In a lighter vein, Austin Patterson, in *Chemical & Engineering News*,[5] called attention to a "honey" from the viewpoint of clarity, namely, the medical term "cheilognathouranoschisis." Wouldn't it have been easier to say "a hare lip combined with a cleft palate"? There are only seven more letters in the descriptive phrase than there are in the medical term.

Continuing in a less serious mood you might like to hear a joke that was published in *Chemical & Engineering News:*

A small businessman wired the Department of Commerce asking if hydrochloric acid could be used to clean a certain type of boiler tube. The answer came back, "Uncertainties of reactive processes make the use of hydrochloric acid undesirable where alkalinity is involved."

"Thanks for the advice," wrote the small businessman. "I'll start using the acid tomorrow." Back from Washington came a night letter: "Regrettable decision involves uncertainties. Hydrochloric will produce submuriate invalidating reactions."

"Thanks again," wrote the small businessman. "Glad to know it's O.K."

This time Washington sent an urgent straight wire: "Hydrochloric acid will eat hell out of your tube."

Now folks, that last sentence is what I mean by plain talk.

Mention was made above of that great scientist Michael Faraday. Let us note an excerpt from his diary. In 1846 he wrote, "All I can say is, that I do not perceive in any part of space whether (to use the common phrase) vacant, or filled with matter, anything but forces and the lines in which they are exerted." What beautiful plain talk, twenty-nine monosyllables and eight bisyllables.

If you have not done so, you will find it interesting sometime to read the *Scientific American*, a magazine which is doing a good job of making scientific matters clear to those with only a relatively elementary scientific background. Waldemar Kaempffert in the *New York Times* uses simple language to acquaint the general public with progress in science.

The Nobel prize for literature last year went to the one who coined these phrases:

"I have nothing to offer but blood, toil, sweat, and tears,"

and again—

"Never have so many owed so much to so few,"

and still again—

"We have not journeyed across the centuries, across the oceans, across the prairies, because we are made of sugar candy."

We cannot all be Nobel prize winners, or Winston Churchills—there can be only one such—but we all can try to talk plain.

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[4] Melba Phillips, "Danger Confronting American Science," *Science*, Vol. 116, p. 442.

[5] Austin M. Patterson, "Words About Words," *Chemical and Engineering News*, Vol. 30, No. 48, December 1, 1952, p. 5086.

TO ASTM MEMBERS:

The summary report of 1953 financial operations is given on p. 37. It is presented in this form to give you a quick appreciation of last year's performance of your Society. Comparison is made with 1952 and with 1950. Since the Book of Standards is issued every three years, a better appraisal can be had by comparing 1953 with 1950, since these are years of larger sales and expenditures.

Your attention is directed to the large increases in gross receipts, favorable operating balance, and net assets. All of this was accomplished with an exceedingly modest increase in the Headquarters' Staff. This cannot, however, go on indefinitely. To handle competently the increasing demands of your Technical Committees and to deal with the complexities of our rapidly expanding technology, further increases in Headquarters' Staff may be necessary.

A portion of the lot acquired in 1950 was sold at favorable terms and the proceeds therefrom, augmented by funds from surplus, were used to purchase a larger property behind 1916 Race St. A large and substantial building thereon is presently undergoing remodeling and will provide for expansion in the foreseeable future.

You will note investments and cash of almost $800,000. To invest these monies to the best advantage, an investment committee has been formed to advise the Finance Committee. Consideration is being given to plans for formula investment.

Your Officers and Staff are alert to the opening-up of new fields of endeavor engendered by our fast expanding technology. New committees are being formed to deal with these matters. There is recognition of the importance of tremendous Government purchases of materials and the need for a closer liaison with Government so that the skills and facilities of ASTM may contribute more to the public good.

Operations for the first three months of 1954 were as favorable as those of the past year. We trust they will continue so. Should there be an industrial recession (and we hope there will not be), it would indeed be short-sighted for industry to retrench in technology, since an expanding technology is the best way to insure a healthy economy.

The Board of Directors extends to the members, workers on committees, and to the Headquarters' Staff its appreciation for the loyal services and splendid cooperation that has made 1953 a successful year.

Sincerely,

L. C. Beard, Jr.,
President.

HIGH LIGHTS, 1953 FINANCIAL OPERATIONS

	1953	1952	% Increase		1950
			1952 Basis	1950 Basis	
Gross Receipts:					
Membership Dues	$233 700	$226 300	3.3	13.6	$205 600
Sales of Publications	512 300	338 500	51.0	57.0	326 000
Other	68 600	83 600	−17.9	9.8	62 500
Total	814 600	648 400	25.7	37.1	594 100
Expenditures:					
Salaries	$237 800	$211 800	12.3	29.4	$184 250
Printing	323 800	259 800	24.7	39.8	231 000
Other	159 500	148 400	7.5	49.8	107 150
Total	721 100	620 000	16.3	37.9	523 200
Favorable Operating Balance	$93 500	$28 400	232.0	31.9	$70 900
Net Assets:					
Real Estate	$244 800	$184 800	32.4	47.3	$166 300
Investments and Cash	776 950	733 900	5.9	46.1	531 500
Equipment	22 800	22 500	1.32	26.7	18 000
Total	1 044 550	941 200	11.1	45.9	715 800
Asset Equity of Each Member	$138	$128	7.8	31.4	$105
Number of Members	7 581	7 342	3.3	11.5	6 797

	1953	1952	1950
Pages of Publications	8 518	15 747	9 461
Number of Employees	60	56	54

ANNUAL REPORT OF THE BOARD OF DIRECTORS

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In the membership and committee membership of the Society are represented a great many talents. It is important and fortunate that this is the case, for with so many diverse activities and the standardization and research work cutting across the whole field of materials, progress must depend upon the skills of those who make up the Society and our technical committees.

That continuing progress can be noted in this report bears testimony to the skills which our large number of working members have, and to the fact that they are willing to put these to use for the benefit of industry and Government and all those concerned with materials. As the talents of any individual are combined with those of another, the fruits become valuable and manifold.

Considering the diversity of our work and the fact that one phase may be of great importance to one group and other activities to others, it is difficult to note any developments that are particularly outstanding. Progress was made along many lines, as will be noted from reviews of the annual reports of the technical committees, from the news articles that appear in the ASTM BULLETIN as a result of committee meetings and their technical activities (the April BULLETIN had 18 pages devoted to a review of ASTM Committee Week), from the steadily increasing number of new specifications and test methods, and from publications, particularly the special technical publications, which continue to be brought out in goodly number.

This report high-lights a number of activities and accomplishments of the past year. There is reference to our healthy financial condition, to the extension of our headquarters properties, and to many successful meetings. The Directors and the Staff have attempted consistently to exercise good stewardship; they have had splendid cooperation from the many workers in the Society.

Applications of Materials:

In last year's report there was brief discussion of the fact that ASTM, frequently looked on as a standardization society or by some as a research organization, is essentially both, but truly it should be looked on as a Society for materials. Our research work provides information and data that frequently is basic in developing specifications or test methods on a sound foundation—these two phases of our work go hand in hand. It may be that in our extensive operations we have not given sufficient attention to the applications of materials, although usage is an important criterion in determining the properties and tests which are part of a specification.

As a result of some discussions in the Board and in other Society groups, it is felt that more emphasis should be given to the applications of materials, and steps are being taken to that end. It is hoped that our districts will from time to time plan technical sessions or even symposiums at which applications are emphasized.

This is not to say that usage has been overlooked, because one can examine almost any symposium or technical paper and find pertinent data on sound applications of materials, but it is felt this phase could be brought more to the forefront. This situation has been reviewed by the Board's Committee on Developmental Activities.

This group also deals with other broad problems. Concerning these it is not difficult in some instances to high-light the problem, but the solution is uncertain or of long duration. For example, there is concern that we may become a group of specialists operating in relatively narrow materials channels. The strength of ASTM does lie in having competent groups concerned with specific fields, but we must continue to develop a broad interest on the part of our members to the end that perhaps the average ASTM member will have more of an over-all interest in our work as a materials society.

The Developmental Committee has made various recommendations to the

Board, some of which are being implemented and others are under study. It is hoped that as facets of this program are accomplished the work of the Society will be even more widely recognized and used.

Headquarters Expansion:

Some details are given in the financial portion of this report, specifically dealing with the Building Fund, to the acquisition of additional property at the rear of the Race St. Headquarters and, concurrently, the sale of a portion of the lot that was acquired two years ago. This move will relieve shortly the crowded situation in the current Headquarters' building and provide for future needs for some time. The financing was handled entirely through the use of Society funds, and no appeal is to be made to the general membership to underwrite this expansion.

New Awards:

It will be noted in the discussion of Honors and Awards that three awards are being made this year for the first time. One of these, established by Mrs. F. E. Richart in honor of the late Professor Richart, will recognize outstanding contributions in the field of concrete and concrete aggregates, the award to be made not oftener than once every three years. The other two are committee-sponsored awards in the fields of soils for engineering purposes and industrial water.

A new Manual on Special Lectures, Honors, and Awards is being issued as a result of intensive studies by a committee of the Board that is studying and coordinating these activities.

Warwick Memorial Room:

The Board has wished to do honor to its former Executive Secretary, C. L. Warwick, who was so long associated with the Society's work during its formative years—first as assistant to the first Secretary-Treasurer, Prof. Edgar Marburg, and subsequently as his successor. A committee appointed shortly after Mr. Warwick's death selected as a most fitting memorial the designation of the present Board Room as the C. L. Warwick Memorial Room. This is a room in the front of the Headquarters Building, overlooking the Parkway and Logan Square. The room was dedicated on May 10 with the unveiling of a portrait of Mr. Warwick and of a bronze plaque commemorating him. Present were Mrs. Warwick and other members of the family, the current officers of the Society, some local past officers who were close to Mr. Warwick, and the Staff.

A special memorial supplement to the ASTM BULLETIN has been prepared, and this will be sent to each member.

Technical Activities

It is estimated that over 6000 technical men serve on the many hundreds of ASTM technical committees and subcommittees. Including subcommittees and sections of the more than 80 main technical committees, there may be 1600 to 2000 working groups. These figures, together with the fact that there are over 2000 specifications, test methods, definitions, etc., and considering the large number of publications sponsored by technical committees, make one realize the astounding diversity and complexity of our technical work. Considering this tremendous scope of our technical work, it is in one sense surprising there are so few administrative problems to be handled by the Board of Directors' Committee on Technical Activities; yet in another sense, considering the loyalty, capabilities, and intensive service that the committee officers and members devote to our work, one might expect that the technical operations would run smoothly.

This portion of the report notes some new activities being considered, details changes of scope which committees have recommended and which have been approved by the Board, and cites certain other facts of interest in this field.

Activities—New or Being Studied:

The Directors are most anxious that the Society shall be alert to new fields of endeavor where its facilities for research and standardization can be of service. At its fall meeting the Board discussed this matter at some length. There was consideration of appointment of a small special group to study continuously this matter, but the complexities of our current industrial activity with its host of problems on materials led the Board to feel that no small group could really encompass the field. Consequently, it stressed the necessity of having three groups alerted, namely, the Directors themselves coming from different industries, the officers of technical and administrative committees, and the Headquarters' Staff. The President directed a communication to all our committee officers, and it is planned that a similar note from time to time will impress these leading technical authorities of the Directors' desire that new problems be brought to our attention for consideration. It seemed patent to the Board that responsibility for alerting the Society must of necessity be spread, and it is confident that the caliber of the men responsible for our work provides reasonable assurance that those companies in industry with materials' problems will know of ASTM's willingness to serve.

Current Situations:

Through its subgroup on Technical Activities the Directors have reviewed a number of situations where one or more men felt ASTM work would be desirable.

Gaskets.—Although Committee D-11 on Rubber and Rubber-Like Materials has carried out work in the field of gasket materials and, largely on the initiative of the Joint Technical Committee on Automotive Rubber, has issued certain standards relating to cork, paper, asbestos as well as rubber, as used in the automotive field, there are other materials that have not been covered, including metallic types. Studies have been under way to elicit the reaction of other groups interested to determine whether a separate committee is indicated.

Flooring Emulsions.—Apparently there is need for research and standardization work to cover flooring emulsions. Two ASTM committees, namely, D-4 on Road and Paving Materials and D-8 on Bituminous Waterproofing and Roofing Materials, are reviewing this problem. It is felt that the work is more nearly akin to that being carried on in Committee D-4, and this group has been asked specifically to consider the matter.

Soil Conditioners.—Announcement has been made earlier of the decision to undertake work on soil conditioners. An organization meeting of a joint ASTM-AOAC (Association of Official Agricultural Chemists) Committee was held on September 3, 1953, at Ohio State University. There are to be three official representatives of ASTM and AOAC to form the nucleus of an executive committee.

Based on recommendations from the members, the ASTM Directors have approved the following statement of scope for this new joint committee:

> *Scope.*—The formulation of specifications and methods of testing for the alteration of physical properties of soil for agricultural and engineering purposes; the stimulation of research to accomplish the foregoing purposes; and the selection of acceptable nomenclature.

There is important work for this group to undertake in developing and clarifying our knowledge of these materials and agreeing on methods of evaluating them.

Miscellaneous.—Other fields where the possibility of standardization work has been reviewed include rocket monopropellants, where there is a committee under Government sponsorship considering standard evaluation tests. The Society's officers have been in touch with this group and offered our services if they can be used appropriately. A group interested in vacuum techniques has been functioning with committees concerned with standards, nomenclature, techniques, etc. Again the Society has offered its facilities.

Other subjects that are being considered in the ASTM standards program include light microscopy, where standards apparently would be constructive, and thermal shock, where a separate committee has been proposed in which among other groups Committee C-22 on Porcelain Enamel is very much interested. Committee E-1 on Methods of Testing is organizing a subcommittee on microscopy and, if the work progresses along lines that indicate the need for a separate committee, the work can be set up as a separate committee. Likewise, Committee E-1 will set up a task group to review the problem of thermal shock.

Because several ASTM committees would be interested in coated fabric test methods, a conference of representatives of the committees on Electrical Insulating Materials, Rubber and Rubber-Like Materials, Textile Materials, and Plastics was held to obtain the various viewpoints and recommend how the work should be handled. It was agreed that Committee D-11 should have primary jurisdiction, with the cooperation of the other interested committees, and the Board has approved this disposition.

Committee D-20 is undertaking an extensive expansion of its work and is reorganizing some of its subcommittees. Five new groups will be appointed to cover tests and specifications for thermoplastic materials, thermosetting materials, plastic pipe and fittings, reinforced plastics, and plastic films and sheeting.

Discussions have been held with the Society of the Plastics Industry in connection with the work on plastic pipe and fittings. It is planned that this subcommittee be set up as a joint committee to undertake the development of tests and specifications for plastic pipe and fittings.

Committee Scopes and Jurisdictions:

Committee E-4 on Metallography:

In order that the statement of scope may indicate more realistically and specifically the work being carried on in Committee E-4 on Metallography, a revised scope has been approved by the committee and by the Board of Directors. The scope will be changed from its present form, namely,

> *Scope.*—Methods and technique of examination of all metallic substances by optical and electron microscopic methods and by X-ray and electron diffraction methods; methods and standards of measurement of grain sizes of and inclusions in metals and alloys; methods and recommendations for photography as applied to metallography; methods of thermal analysis of metallic materials; definitions of terms relating to metallography.

to read as follows:

Scope.—Methods, recommended practices, and standards for the entire field of metallography, including: the selection, preparation, and manipulation of samples; the equipment and techniques for examining structure and structural phenomena and metallic substances by such means as optical and electron microscopy, X-ray and electron diffraction, microradiography, micro-hardness determinations, thermal analysis, etc.; and the establishment of nomenclature and definitions of terms relating to metallography.

Committee C-11 on Gypsum:

To provide for coverage of aggregates used with gypsum and gypsum products, these materials will be added to a revised scope of Committee C-11, which now reads as follows:

Scope.—The formulation of specifications, methods of test, and definitions relating to gypsum, calcined gypsum, gypsum products, and aggregates for use therewith.

Committee B-4 on Electrical Heating, Resistance, and Related Alloys:

To more adequately describe its coverage in the electrical field, Committee B-4 revised its title and scope as follows:

Title.—Committee B-4 on Metals for Electrical Heating, Electrical Resistance, and Electronic Applications.

Scope.—In general, Committee B-4 has jurisdiction over the classification, specification requirements, methods of test, questions of utility, and related subjects pertaining to wrought and cast metallic materials and parts for electronic and electrical resistance applications, for the structure and containers of electric furnaces, thermostatic metals and alloys, metallic materials for electronic devices and incandescent lamps, and for electrical contacts.

Committee C-15 on Manufactured Masonry Units:

The committee has revised its scope to include the field of waterproofing materials used in connection with masonry walls as well as to express more simply its full coverage. This new scope is as follows:

Scope.—Formulation of specifications, methods of tests, and definitions relating to masonry units manufactured from clay, sand-lime, and concrete; and for waterproofing materials, other than of a bituminous nature, for unit masonry walls. The masonry units shall not include natural building stone or slate nor products for use as refractories.

Committee D-6 on Paper and Paper Products:

A condensed and clarified scope of Committee D-6 has been approved, as follows:

Scope.—Development of specifications, methods of sampling and testing, and definitions of terms pertaining to paper and paper products.

Committee C-21 on Ceramic Whiteware:

In order that this committee may include in its studies certain products that are similar to ceramic whiteware but are not classified as such, for example, stoneware, terra sigillata, ironstone ware, Rockingham ware, basalt ware, etc., the phrase "and similar products" has been added to the scope of this committee, which will now read as follows:

Scope.—The stimulation of research and the formulation of definitions, methods of tests, and specifications pertaining to ceramic whiteware and similar products.

Dewey Decimal System:

The suggestion that the Dewey Decimal System be adopted in the numbering of paragraphs in ASTM standards was considered by the Directors. The decision was reached that the use of this system would not have any particular advantage to commend it because of the varied nature of ASTM standards and that it certainly would not justify the heavy cost of having the type for our standards reset and the expenditure of Staff time in re-editing.

Regulations Governing Advisory Committee on Corrosion:

In the Regulations Governing the Advisory Committee on Corrosion, which committee is concerned with the coordination of corrosion investigations, researches, and test procedures sponsored by the technical committees of the Society, there is a provision that the committee is to review all reports of investigations concerning corrosion. This requirement it is felt is impractical and, further, that the technical committees doing the work and preparing the reports are in the best position to judge their adequacy. Accordingly, on recommendation from the Advisory Committee, there is being deleted from the regulations as published in the ASTM Year Book Sections 5(*d*) and 6(*d*), the remaining sections to be renumbered accordingly.

Research Activities:

There are dozens of research projects constantly under way in technical committees, and there are others that may have been instigated by a committee that are receiving wider support. Many of these are noted in the report of the Administrative Committee on Research, with details covered in the reports of the respective technical committees responsible. One project should be noted here, namely, the work on wood poles being carried out under the auspices of ASTM Committee D-7 on Wood and now under way at the Forest Products Laboratory. Some 600 full size poles are to be tested with thousands of small clear specimens. Among the objectives are the evaluation of the possibility of determining the strength of full size poles from smaller specimens and also the development of stress data that should result in extensive savings from the possible use of smaller size poles. The two-year project is estimated to cost about $150,000, and while this sum has not yet been completely raised, the goal is not far off. A number of leading trade and technical groups and industrial companies are cooperating.

Manual for ASTM Committee Officers:

There has been under development a Manual for Committee Officers. The Staff has devoted considerable time and effort to this, and copies have been distributed to the chairmen and secretaries of the main technical committees for comment. This is intended to provide in reasonably compact form information on a host of responsibilities and problems which committee officers must handle. It covers many points not listed in the printed Regulations Governing Technical Committees as shown in the Year Book. When approved it is expected the Manual will be published and made available on request.

50-Year Anniversaries:

Several of the Society's technical committees were established in 1904. Of these, Committee D-2 is planning a suitable celebration later in the year. Committee D-4 held appropriate ceremonies at its meeting during ASTM Committee Week in Washington. These committees, the largest in this group, have made outstanding contributions to the fields covered and are to be congratulated on their record. The work of Committee D-4 is recognized throughout the highway field. The Petroleum Committee has a very large number of technical men in the industry working on its myriad technical committees, divisions, and subcommittees. In addition to over 175 widely used standards, the committee has sponsored the publication of many important books. A summary of some of the recent D-2 sponsored publications will appear in a forthcoming issue of the ASTM BULLETIN.

ASTM MEETINGS, JUNE 1953-JUNE 1954, INCLUSIVE.

Meeting	Place and Date	Notes
Annual Meeting	Atlantic City, N. J. Chalfonte-Haddon Hall June 28-July 3, 1953	34 Technical Sessions; 550 Committee Meetings; 62 New Tentatives Approved. (Registered Attendance 2470—445 Ladies)
ASTM Committee Week	Washington, D. C. Shoreham Hotel February 1-5, 1954	427 Committee Meetings. (Registered Attendance 1400)
Spring Meeting	Washington, D. C. Shoreham Hotel February 3, 1954	Symposium on Design of Experiments. Symposium on Color of Translucent Products. Dinner: "Standardization in the Department of Defense," Charles S. Thomas.
District or Local (sponsored by Councils indicated)	Philadelphia, Pa. Franklin Institute September 18, 1953	Joint meeting with Philadelphia Section, National Association of Corrosion Engineers. "Copper and Copper Alloys," C. L. Bulow.
	Cambridge, Mass. (New England) Commander Hotel October 8, 1953	"The Romance of Trace Chemistry," Dr. John Sterner.
	St. Louis, Mo. Engineers' Club October 15, 1953	Joint meeting with St. Louis Chapter, American Society for Metals, and Engineers' Club of St. Louis. "Silicon Steel," William Jones.
	New York, N. Y. Engineering Societies Bldg. October 20, 1953	President's Night: "Something Has Been Added," President L. C. Beard, Jr.[a]
	Pittsburgh, Pa. Mellon Institute October 27, 1953	Joint meeting with Pittsburgh Section, Society of Automotive Engineers. "Something Has Been Added," President L. C. Beard, Jr.[a]
	Indianapolis, Ind. (Ohio Valley) McClarney's Famous Restaurant November 6, 1953	Joint meeting with Indianapolis Chapter, American Society of Lubrication Engineers. "Something Has Been Added," President L. C. Beard, Jr.[a]
	Berkeley, Calif. (Northern California) University of California November 12, 1953	Joint meeting with California Section, American Chemical Society, and Northern California Section, American Institute of Chemical Engineers. "An Excursion in Petroleum Chemistry," F. D. Rossini.[b]
	Los Angeles, Calif. (Southern California) Rodger Young Auditorium November 13, 1953	Joint meeting with Southern California Section, American Chemical Society. "An Excursion in Petroleum Chemistry," F. D. Rossini.[b]
	Houston, Tex. (Southwest) University of Houston November 20, 1953	Joint meeting with Southern Texas Section, American Chemical Society; South Texas Section, American Institute of Chemical Engineers; and Southern Texas Section, American Society for Quality Control. "An Excursion in Petroleum Chemistry," F. D. Rossini.[b]
	New York, N. Y. Consolidated Edison Co. of New York, Inc., Auditorium November 18, 1953	Joint meeting with New York Section, American Society of Lubrication Engineers. "Rust Prevention Practices in Manufacturing Operations," C. R. Gillette.
	Philadelphia, Pa. Franklin Institute January 27, 1954	"Non-Destructive Testing," S. A. Wenk. "A Day With the D.A.," Marvin R. Halbert.
	Buffalo, N. Y. (Western New York-Ontario) Hotel Westbrook February 10, 1954	President's Night: "Something Has Been Added," President L. C. Beard, Jr.[a]
	St. Louis, Mo. Forest Park Hotel February 12, 1954	"Something Has Been Added," President L. C. Beard, Jr.[a]
	Dallas, Tex. (Southwest) Amon Carter Airport February 15, 1954	"Something Has Been Added," President L. C. Beard, Jr.[a]
	Houston, Tex. (Southwest) University of Houston February 17, 1954	"Something Has Been Added," President L. C. Beard, Jr.[a]

ASTM MEETINGS, JUNE 1953-JUNE 1954, INCLUSIVE—*Continued.*

Meeting	Place and Date	Notes
	Alhambra, Calif. (Southern California) C. F. Braun & Co. February 23, 1954	Joint meeting with Southern California Section, American Institute of Chemical Engineers. "Something Has Been Added," President L. C. Beard, Jr.[a]
	Berkeley, Calif. (Northern California) University of California February 25, 1954	Joint meeting with California Section, American Chemical Society, and Northern California Section, American Institute of Chemical Engineers. "Something Has Been Added," President L. C. Beard, Jr.[a]
	Richland, Wash. Cafeteria of Chief Joseph High School March 2, 1954	Joint meeting with Columbia Basin Chapter, American Society for Metals; Columbia Basin Section, American Society of Mechanical Engineers; Columbia Basin Section, American Institute of Chemical Engineers; and Richland Section, American Chemical Society. "Something Has Been Added," President L. C. Beard, Jr.[a]
	Tacoma, Wash. New Yorker Cafe March 4, 1954	Joint meeting with Tacoma Engineers Club; American Chemical Society; and American Institute of Chemical Engineers. "Something Has Been Added," President L. C. Beard, Jr.[a]
	Wilmington, Del. (Philadelphia) Hotel duPont March 17, 1954	Joint meeting with Delaware Section, American Chemical Society. "Something Has Been Added," President L. C. Beard, Jr.[a]
	Detroit, Mich. Horace H. Rackham Educational Memorial March 31, 1954	"Something Has Been Added," President L. C. Beard, Jr.[a] "Standardization and Materials Research March On," Executive Secretary R. J. Painter.
	St. Louis, Mo. Engineers' Club April 14, 1954	"Non-Destructive Testing," S. A. Wenk.
	New York, N. Y. Fraunces Tavern April 13, 1954	Joint meeting with Metropolitan District, Empire State Section, Technical Association of the Pulp and Paper Industry. "Insulating Paper for High Tension Cables," William A. Del Mar. "Voices in Paper," film.
	Storrs, Conn. (New England) University of Connecticut April 22, 1954	"Some Highlights of Petroleum Technology," President L. C. Beard, Jr. "By-Products of Earthquakes," Rev. Daniel Linehan, S.J. "Measurement of Strains in Reinforcing Steel in Reinforced Concrete," Lyle K. Moulton.

[a] President Beard's talk, various versions of which were presented at District Meetings, was published in ASTM BULLETIN, No. 198, May, 1954, p. 51 (TP 97).

[b] The address by F. D. Rossini was a condensed version of his 1953 Edgar Marburg Lecture, "An Excursion in Petroleum Chemistry," *Proceedings*, Am. Soc. Testing Mats., Vol. 53, p. 545 (1953); also issued separately.

District and Related Activities

During the year the activities of the various districts have continued to occupy an important place in advancing the work of the Society. Although these efforts largely are concentrated on local meetings, nevertheless the district councils in Washington, Chicago, and on the West Coast are cooperating in national meetings.

From the accompanying table it will be noted there was a total of 25 meetings held under district or related auspices. In three areas, Indianapolis, Dallas, and Tacoma-Seattle, our members were together locally for the first time. Some of the meetings were marked by excellent attendance, as indicated in the table.

President Beard, continuing the practice established by preceding presidents, was the chief speaker at many of the district meetings, including those noted above that were held for the first time.

The latest district established last year in the Southwest has had an active year and is planning to stimulate further active interest in the Society work in this important area.

Concerning national meetings, the Washington District arranged the dinner meeting and social hour during Committee Week in February, where there were present leaders in Government standardization work. The Chicago District Council provided the nucleus for the Committee on Arrangements for the 1954 Annual Meeting and is sponsoring a special session on the philosophy of specifications.

Looking ahead to 1956 there is being organized a General Committee on Arrangements for the Society's Second Pacific Area Meeting in which both the Southern and Northern California District Councils are participating actively. This meeting will be in Los Angeles.

National Meetings

The Society's 56th Annual Meeting held June 28–July 3, in Atlantic City, N. J., was attended by almost 3000 members, committee members, and visitors, including about 450 ladies. Actual registration for the week for the men was 2470. To provide adequate time for the presentation of the some 131 technical papers and various reports, 34 technical sessions were held, including seven evening sessions. There were about 550 technical committee meetings. Outstanding features of the meeting, including the various awards that were made and some of the outstanding technical accomplishments, have been recorded in issues of the ASTM BULLETIN and in the Summary of Proceedings distributed to all members.

The Philadelphia District arranged a very interesting program for the ladies throughout the week and also sponsored the annual dinner with its entertainment and dance.

The 1954 ASTM Committee Week and Spring Meeting were held considerably earlier than usual, in line with the decision reached after consulting with the technical committees that a meeting in very early February would be more convenient and practical. This meeting was held in Washington during the week of February 1. While total registration depends upon the committees participating, the attendance was the largest of any committee week yet held—some 1400—and there were over 400 committee meetings. Two symposiums were held as part of the Spring Meeting—one on Design of Experiments and the other on Color of Transparent, Translucent Products.

The Washington District took advantage of the occasion to sponsor a special dinner at which there were present as guests of the Society a number of Government leaders concerned with standardization and materials activities. The feature address of the evening, a very pertinent one because of the emphasis on standards activities, was made by Mr. Charles S. Thomas, then Assistant Secretary of Defense, Logistics and Supply, but appointed subsequently as Secretary of the Navy. This address was published in the April BULLETIN.

Future Meetings:

The 1955 Annual Meeting will be held in Atlantic City, June 26–July 1, and the 1956 Annual Meeting, again at Haddon Hall, will be earlier in the month—June 17–22. An effort is made in scheduling these meetings to avoid conflicts with other societies whose members are concerned with our work, but it is not possible to avoid all of them since quite a number have annual or summer meetings in June.

The 1955 Committee Week and Spring Meeting will be in Cincinnati, Ohio, January 31–February 4. The 1956 Committee Week is scheduled for Buffalo the last week in February, to avoid weather conditions that might prevail there earlier in the month.

1956 Pacific Area Meeting:

The General Committee on Arrangements for the Society's Second Pacific Area National Meeting to be held in Los Angeles, September 16–22, 1956, is making plans for various events. The officers of the committee, which include representatives of both the Southern and Northern California District Councils, met earlier this year when the President and Executive Secretary were on the West Coast. At that time subcommittee officers were selected, and the personnel of the groups is to be completed soon.

Publications

In order that maximum benefits shall come from the intensive research and standardization activities of the Society, it is essential that the standards and the technical papers and reports containing the data be widely disseminated. The inventory records of our publications and the statistics on proceeds from the sale of our books indicate that they have been very widely distributed. This applies alike to the books containing standards—for example, the 1953 Supplement to the Book of Standards—the special compilations of standards of which there are an increasing number, and the special technical publications and miscellaneous books.

The attached report of the Administrative Committee on Papers and Publications (see Appendix IV) lists all of the publications issued and gives some indication of the volume of material published. While the current records are not so impressive as the 1952 figures because that year included the new edition of the Book of Standards, nevertheless it will be noted that they aggregate over 8000 pages. Many significant special technical publications, largely sponsored by technical committees, have been issued. These books and pamphlets are the more authoritative because the papers have been reviewed by one or more other authorities in the field, and the authors are given the opportunity of a last-minute review of proofs to ensure both accuracy and the inclusion of the latest material.

An effort is made to keep members fully posted on new and revised publications through brief discussions that appear in the ASTM BULLETIN, and members and others receive through the mail notices covering our publications.

Membership

On May 1, 1954, the membership of the Society totaled 7615, compared with a total of 7522 one year ago. Gains and losses in various classes of membership are shown in the following table:

Class of Membership	Membership		Losses				Additions		Total		
	June 1, 1953	May 1, 1954	Resignations	Dropped	Death	Transfer	Transfer	Election	Loss	Gain	Increase
Honorary	20	20	...	...	2	...	2	...	2	2	...
Perpetuity and Life	11	11	...	...	...	...	...	...	...	...	...
Sustaining	270	274	2	...	...	1	6	1	3	7	4
Company, Firm, etc.	1784	1788	49	15	...	15	7	76	79	83	4
Individual, etc.	5333	5433	216	101	40	9	36	430	366	466	100
Junior	104	89	7	10	...	27	1	28	44	29	15[a]
Total	7522	7615	274	126	42	52	52	535	494	587	93
Student	323	359	22	174	...	13	...	245	209	245	36

[a] Net loss.

It will be noted that 535 new members were elected during the 11-month period, compared with 674 for the preceding (full) year. Because of the shorter period covered in this 1954 report (due to earlier scheduling of the Annual Meeting), it is difficult to offer significant comments and, of course, a true comparison cannot be made. It is hoped that the rather heavy losses from resignations, delinquencies, and deaths (totaling 442 over the past 11 months, compared with 402 the previous year) may be offset by consistent accretions during the remainder of the 1954 fiscal year.

It is interesting to compare our present membership of 7615 with the figures for ten and twenty years ago; in 1944 our total membership was 5257, and in 1934 it was 3569. A true comparison would, of course, need to consider the relative percentages of sustaining, company, and individual memberships. Nevertheless, the steady growth in the total membership is encouraging.

Sustaining Members:

There have been seven new sustaining members, two resignations, and one sustaining member transferred to company class. The new sustaining members are:

Diamond Alkali Co.
Durez Plastics and Chemicals, Inc.
Globe Steel Tubes Co.
Lock Joint Pipe Co.
Riley Stoker Corp.
Southern California Edison Co.
Spang-Chalfant, Division of The National Supply Co.

50-Year Members:

There are nine individuals and companies as noted below that have been connected with the Society continuously for 50 years, having joined in 1904.

Robert A. Cummings
Alfred E. Roberts
Herbert L. Sherman
Frank N. Speller
Dominion Bridge Co., Ltd.
Froehling & Robertson, Inc.
Illinois Central Railroad Co.
Tufts College Engineering School
Westinghouse Electric Corp.

These members will be recognized at the Annual Meeting.

40-Year Members:

There is a total of 22 members who this year have completed 40 years of membership, which brings the total number of certificates issued to the "Forty-Year Club" to 273. The members who will receive the 40-Year Certificates at this Annual Meeting are as follows:

American Institute of Architects, Department of Education and Research
Benjamin A. Anderton
A. M. Byers Co.
C. H. Crawford
Detroit Steel Corp., Portsmouth Division
Arno C. Fieldner
Harrison F. Gonnerman
The Goodyear Tire and Rubber Co.
Grand Rapids Plaster Co.
L. C. Hewitt
A. L. Kuehn
Mason City Brick and Tile Co.
H. S. Mattimore
University of Minnesota Library
Norton Co.
The Okonite Co.
Republic Steel Corp.
The Riverside Metal Co.
Leland S. Rosener
SKF Industries, Inc.
Underwriters' Laboratories, Inc.
Albert E. White

Deaths:

The Society has lost the following 42 members through death (figures in parentheses are dates of membership):

Bienfait, J. L. (1946)
Brandeberry, John B. (1945)
Burgess, C. O. (1949)
Clayden, A. Ludlow (1924)
Demarest, W. G. (1939)

Diskant, Eugene M. (1951)
Ericson, Harry L. (1950)
Hall, John Howe (1910)
Hamilton, Chester B., Jr. (1937)
Heydegger, Helmut (1948)
Hilts, Harold E. (1914)
Howard, Ernest E. (1927)
Huber, Charles J. (1942)
Hughes, Ben H. (1950)
Jeffers, Paul E. (1945)
*Jones, L. B. (1937)
Judson, Dwight Rist (1919)
Ketchbaw, Thomas D. (1941)
Knickerbocker, C. J. (1940)
*Lawson, Thomas R. (1909)
MacLaren, F. H. (1951)
Mantz, Victor M. (1941)
Mark, Francis L. (1945)
McGervey, William P. (1952)
Miller, George W. (1951)
Mundt, Herbert W. (1940)
Paine, J. J. (1922)
Powell, Nelson M. (1924)
Sanford, Edward R. (1948)
Sedwick, T. D. (1916)
Segal, David (1938)
Sheehan, John P. (1949)
Steigerwalt, Robert W. (1919)
Stewart, Clifford Richard (1932)
Tolson, O. T. (1946)
Tuscany, Arthur J. (1935)
Varela, Oscar Rey (1953)
Wait, Bertrand H. (1931)
Whelan, John E. (1947)
White, Alfred H. (1909)
White, Lazarus (1937)
Wright, Calvert C. (1949)

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* Honorary Member.

In addition to the above, the following representatives of company members of the Society passed away:

Cole Coolidge, E. I. du Pont de Nemours and Co., Inc.
S. G. Flagg, Stanley G. Flagg and Co., Inc.
Allan M. Hirst, Lock Joint Pipe Co.
A. C. Jessup, Magnesium Elektron, Ltd.
A. A. Klein, Norton Co.
J. M. Matson, National Institute of Drycleaning
L. W. Mesta, Mesta Machine Co.
R. A. Moncrieff, Charles T. Main, Inc.
Ezra Mosher, National Motor Bearing Co., Inc.
R. W. Parsons, The Ohio Brass Co.
H. G. Swan, Symington-Gould Corp.
Leo L. Vasold, Electric Auto-Lite Co.

A number of these men have been affiliated with the Society for many years and rendered outstanding services, particularly through work on the technical committees. The notable work and meritorious service of two of the men, Lloyd B. Jones and Thomas R. Lawson, had been recognized through election to Honorary Membership in the Society. Professor Lawson, engineering consultant and retired Head of the Department of Civil Engineering, Rensselaer Polytechnic Inst., was a Past-President of the Society and a valued contributor to the work of former Committee C-3 on Brick, which he headed for eight years, and also to activities in Committee C-15 on Manufactured Masonry Units. Mr. Jones, retired Engineer of Tests, Pennsylvania Railroad Co., and consulting engineer, was honored posthumously at the 1953 Annual Meeting for important contributions in both administrative and technical phases of the work. A Past-Director, he had been chairman of the Administrative Committee on Standards for several years and also had served on the Committee on Simulated Service Testing. An expert on materials used in the railroads field, Mr. Jones' most intensive technical work was concentrated in Committee A-1 on Steel.

Charles O. Burgess, internationally known metallurgist and Technical Director, Gray Iron Founders' Society, had been especially active in Committees A-3 on Cast Iron and A-7 on Malleable-Iron Castings, serving as Secretary of the former and Chairman of the latter for periods of several years. He was Vice-Chairman of the Cleveland District Council at the time of his death. W. G. Demarest, Manager, Clay Products Assn. of the Southwest, had participated actively in the Committee on Manufactured Masonry Units, serving as Chairman of the Subcommittee on Structural Clay Tile. John Howe Hall, outstanding authority in metallurgical engineering and steel foundry practice and pioneer in the heat treatment of steel, rendered valued service in committees concerned with ferrous materials, metallography, and non-destructive testing. Paul E. Jeffers, prominent structural engineer, had been active in the organizational work of the Southern California District, serving as Chairman from 1931–1934.

John J. Paine, of the Bureau of Tests, Pittsburgh Department of Public Works, served for many years on the committees concerned with concrete and road and paving materials; he also was an officer of the Pittsburgh District. R. W. Steigerwalt, retired Metallurgical Adviser, Railroad Materials and Commercial Forgings, United States Steel Corp., had been elected to honorary membership in Committee A-1 on Steel in recognition of valued contributions to the projects of that group, especially in activities concerned with steel forgings and rolled steel wheels.

Arthur J. Tuscany, consultant on association management, had been very active for many years in the Cleveland District Council, serving terms as Secretary (1934–1940) and as Chairman (1940–1950). A. H. White, Professor Emeritus of Chemical Engineering, University of Michigan, and pioneer in the introduction of the science of chemical engineering to the manufacture of gas and coke from coal, had been active in the work of Committees D-5 on Coal and Coke and D-19 on Industrial Water.

A. A. Klein of the Norton Co., a leading scientist in the abrasive industry, participated for many years in the work of Committee B-8 on Electrodeposited Metallic Coatings and had been an important contributor to the activities of Committee E-1 on Methods of Testing, serving as Chairman of the Subcommittee on Sieves. He also had rendered valued aid in activities of the New England District.

Honors and Awards

Announcement was made last year of a new Board committee on Lectures and Awards. This group was charged with coordinating the various awards and honors that are made in behalf of the Society, reviewing recommendations from the committees on selection of lecturers, and in general serving as an arm of the Board in seeing that the procedures are consistent. The committee has already made several recommendations to the Board to simplify mechanics of selecting winners of awards made for outstanding papers; shortly it will issue a Manual on Special Lectures, Honors, and Awards which should be of real service to the various committees who must make selections and in fact to all who are interested in this phase of the Society's operations.

While the general purpose of all the various awards, including the three new ones that are instituted this year, is to recognize leaders in special fields, each of them tends to stimulate interest in the particular work being recognized.

The Board has continued recognition for outstanding service through the selection of members to receive the Award of Merit. Various awards and medals are also given to recognize outstanding papers and to foster research in certain special fields.

New Awards.—As indicated three awards are being given this year for the first time. One of them, the Frank E.

Richart Award, commemorates the late Professor Richart who did outstanding work in the field of concrete and concrete aggregates. The other two are committee-sponsored awards in the fields of soils for engineering purposes (Committee D-18) and industrial water (Committee D-19).

Award of Merit:

The Award of Merit Committee for 1954, comprising A. T. Goldbeck, chairman, H. L. Maxwell, D. C. Scott, Jr., C. R. Stock, and H. W. Stuart, reviewed suggestions and citations from various technical committees and nominated eleven members who by unanimous action of the Board were voted the 1954 Awards of Merit. Each one has contributed in an important way to the work of the Society. Award of Merit certificates will be presented during this Annual Meeting to the following:

Harvey A. Anderson
Benjamin A. Anderton
James Aston
Robert F. Field
Oliver M. Hayden
Earl F. Kelley
Gordon M. Kline
Stewart S. Kurtz, Jr.
Ernest E. Thum
Sam Tour
Herbert L. Whittemore

Recognition of Technical Papers:

The following awards will be made at this Annual Meeting in recognition of outstanding technical papers:

Charles B. Dudley Medal—presented for a paper of outstanding merit constituting an original contribution on research in engineering materials. Medals this year will be presented to C. E. Work and T. J. Dolan of the University of Illinois for their paper on "The Influence of Strain-Rate and Temperature on the Strength and Ductility of Mild Steel in Torsion."

Richard L. Templin Award—presented for a paper describing new testing methods and apparatus, the purpose of the award being to stimulate research in the development of testing methods and apparatus. This year the award will be made to E. T. Wessel and R. D. Olleman of Westinghouse Corp. for their paper entitled "Apparatus for Tension Testing at Subatmospheric Temperatures."

Sam Tour Award—presented for a paper describing new and useful testing procedures, apparatus, or new and useful evaluation of previously developed corrosion testing methods, the purpose of the award being to encourage research on the improvement and evaluation of corrosion testing methods and to stimulate the preparation of technical papers in this field. This year the award will be made to John T. Richards of Penn Precision Products (formerly with The Beryllium Corp.), for his paper entitled "The Corrosion of Beryllium Copper Strip in Sea Water and Marine Atmospheres."

Sanford E. Thompson Award—presented for a paper of outstanding merit in the field of concrete and concrete aggregates. The committee is making no recommendation for an award this year.

C. A. Hogentogler Award—presented for a paper of outstanding merit on soils for engineering purposes. This award was established in 1954 by Committee D-18 on Soils for Engineering Purposes in honor of its first chairman, C. A. Hogentogler, and it is expected the first award will be made this year.

Recognition of Outstanding Contributions:

The Harold DeWitt Smith Memorial Medal—presented for outstanding achievement in the field of textile fiber science and utilization. The medal this year was awarded to A. G. Ashcroft, Vice-President of Research and Development, Carpet Division, Alexander Smith, Inc., at the March meeting of Committee D-13 on Textile Materials.

Frank E. Richart Award—presented to recognize outstanding contributions made in the field of concrete and concrete aggregates. This award was established in 1954 by the Board through a gift from Mrs. F. E. Richart, to honor and perpetuate the memory of her late husband, a long-time member of the Society, a member and officer of various technical committees, a Vice-President, and Honorary Member of the Society. It is to be given not oftener than once every three years. The first award will be made to Albert T. Goldbeck, National Crushed Stone Assn.

Max Hecht Award—presented in recognition of outstanding service to Committee D-19 on Industrial Water in the advancement of its objective—the study of water as an engineering material. The award was established by the committee in 1954 in honor of its first chairman, Max Hecht, who is to be the recipient of the first award.

Finances

Report for the Fiscal Year of 1953:

The annual statement of the finances of the Society is presented in the form of the report of the auditors for the fiscal year 1953, which appears in Appendix I. The report gives the balance sheet of assets and liabilities, including general funds, building fund, and other special and designated funds; a statement of receipts and disbursements classified into "operating" (budgeted) and "nonoperating"; details of the building fund and of special funds; and investments of Society funds.

Operating Receipts:

Total operating receipts were $814,640. Of this amount receipts from dues and entrance fees were $233,705 or 28.7 per cent; receipts from sales of publications were $512,262 or 62.9 per cent; and receipts from miscellaneous sources consisting principally of advertising, income from investments, and registration fees totaled $68,673 or 8.4 per cent.

With publication sales at such a high figure largely because of the demand for the 1952 Book of Standards, the ratio of income is changed considerably from previous years; whereas income from dues has normally been well above 30 per cent, this year it is 28.7 per cent as indicated. We had confidently expected income from the 1952 Book of Standards to reach at least $180,000 and it was actually about $233,000. Other large items were sales of special compilations of standards and special and miscellaneous publications including the Special Technical Publication series, the latter accounting for almost $93,000.

Operating Disbursements:

Total disbursements for the year are shown as $721,123 which includes $60,000 earmarked but not spent for the 1955 Book of Standards. While several major items were under the budget, our publication costs exceeded our estimates, particularly special and miscellaneous publications. This estimate is likely to vary depending on the number of symposiums held, the dates of completion, and the volume of the numerous STP's and related items. Two items particularly sent publication costs over the figure budgeted, namely, the ASTM-British Petroleum Measurement Tables and the newly-set and fairly expensive grouping of Spectrographic Standards. Total cost of special and miscellaneous publications was about $75,000, but our income from these sources was almost $93,000. The Year

Book continues to cost us close to $13,000 for the 7400 copies printed, but this is considered a very valuable publication for our members. Including the $60,000 earmarked but not spent as a reserve for the 1955 Book of Standards, our total publication costs were almost $324,000, about 49 per cent of all disbursements.

Total salaries, $237,761, were about $10,500 under the budget. Total retirement, insurance, and health expenses were over the budget somewhat because of the added cost of the Blue Cross and Group Life Insurance instituted by the Directors for the Staff during the year. Salaries accounted for about 36 per cent of disbursements, which compares with ratios for previous years of about 35 per cent.

With greatly increased sales of publications and higher rates for parcel post, the total general office expenses were over the budget by about $8000. (For 1954 we have $35,000 included for postage and expressage, a sizable sum.)

Summary of 1953 Operations:

Comparing operating receipts with disbursements, there was a favorable balance of $93,517. While this is very encouraging, it should be remembered that our budgetary operations really need to be considered over a three-year period corresponding to the Book of Standards years. The heavy demand for this book immediately after publication usually results in a very favorable year with the two ensuing years likely to reflect lessened demand for the book, and as noted in the discussion of our 1954 budget, a deficit is anticipated for the current year.

Because of the uncertainty of current operations, it was decided to allocate directly to the Society's general surplus the 1953 favorable operating balance so that it can be drawn on conveniently. This means that the Society's surplus in General Funds at the end of 1953 totals $348,604, which is just over half of the actual disbursements for 1953. Corresponding figures for the surplus for the preceding two years are $265,824 and $259,063 respectively.

Balance Sheet.—The appended auditors' report includes a balance sheet of assets and liabilities as of December 11, 1953. Assets in the General Funds totaled $612,858 compared to $568,558 a year ago. Total assets including the Building Fund and Special and Designated Funds are $1,195,404 compared to $1,004,217 a year ago. It should be pointed out that in the Balance Sheet no account has been taken of the assets of the Society in the form of publications in stock. This is consistent with many years' practice in this respect and, of course, results in a more conservative statement. An inventory of the principal technical publications as of April 26, 1954, is summarized below:

Proceedings (All back copies not incl. 1953)	2 227
1952 Book of ASTM Standards	
Part 1	2 530
Part 2	2 879
Part 3	2 377
Part 4	2 513
Part 5	3 001
Part 6	2 065
Part 7	2 642
1953 Supplement to Book of Standards	
Part 1	5 163
Part 2	3 878
Part 3	4 283
Part 4	3 192
Part 5	3 131
Part 6	3 027
Part 7	3 067
ASTM Methods of Chemical Analysis	1 331
Special Compilations of Standards	14 147
Selected Standards for Students	14 945
Symposiums and Special Reprints	130 827
Reprints of Standards (Approx.)	215 000
Radiographic Standards for Aluminum and Magnesium Castings	22

Not included in inventory
- (1) Viscosity Temperature Charts
- (2) Hardenability Charts
- (3) Knock Test Manual and Supplement
- (4) Marburg Lectures
- (5) Cotton Yarn Boards
- (6) Petroleum Charts

ASTM Building Fund.—Although the auditors' report contains a statement of receipts and disbursements and the Balance Sheet for the ASTM Building Fund which this year is offered in a more simplified form than previously, a statement on real estate transactions which took place last year may aid in understanding some of the data.

It was obvious a few years ago that if the rate of the Society's growth continued with consequent expansion in the Headquarters' Staff and the necessity for more ample storage space for publications and office equipment, etc., the present Headquarters' Building would not be adequate. Therefore, when there was the opportunity to procure a lot immediately at the rear of the present building and also behind a portion of the Academy of Natural Sciences, our next door neighbor, this lot was procured at a total cost, including commission and settlement fees, of $29,179.

Since it was felt many advantages might accrue to the Society, the Academy of Natural Sciences, and our other neighbor, the Moore Institute of Art, the very fine girls' school whose dormitories constitute the rest of the block facing on Race Street, several friendly discussions took place on the possibility of sharing the cost for additional property in this block. However, the Moore Institute's plans for a large and complete new building were at a point where they felt it was not feasible to change them. Their plans envisage a new six- or seven-story building extending from the west line of our property to 20th St., to consist of dormitories, classrooms, and all other facilities needed by the art school. This will be an imposing structure to cost in the neighborhood of about $3,000,000.

Our Special Committee on Headquarters' Expansion meanwhile had considered future needs and the best means of providing for them. When the Academy of Natural Sciences made strong pleas for us to sell them a portion of our lot so that they could square off their property for future building expansion, we made overtures to the owners of another property at the rear of our building; this property consists of a large garage, office space, and other structures. As a result of summer-long negotiations this building and land, fronting about 90 ft on Cherry St. and extending back to Quarry St. at the rear of our present building, were procured, and we then concurrently sold about three fourths of our 80-ft lot to the Academy. The latter agreed to collaborate with us in the potential closing of Quarry St. at the rear which would give us extra land and permit us to connect the present building on Race St. with the Cherry St. property. The cost of the Cherry St. property was $81,500 and with fees totaled $87,100.

We received $35,000 from the sale of three fourths of our lot and used these proceeds to wipe out a combined note that had been held by the Society's General Funds on the current building and the lot.

The Balance Sheet for the Building Fund reflects these various transactions. To help defray costs of rehabilitating the Cherry St. building, General Funds, in wiping out the note it held, contributed the proceeds from the sale of the lot to enhance the Building Fund. It will be noted the latter includes cash of $63,600 and securities totaling $13,633.

Assets in the Building Fund, which include the current Race St. Headquarters, the Cherry St. property, and the balance of the lot immediately adjoining this, total $322,045.

As liabilities the Balance Sheet shows all contributions from members and from other ASTM funds, accumulated income, interest, proceeds from the lot sale in excess of the cost, and the loan from ASTM General Funds which enabled the procurement of the Cherry St. property; the latter totals $87,100.

The Finance Committee felt that we should procure this additional property using current funds. This note or loan is to be amortized on a 10-year basis, and no interest will be charged the

Building Fund for the loan. Depreciation of the Cherry St. property is to be on a 30-year basis.

It might be explained further that the Building Fund receives as current income from the Society's General or Operating Funds annual payments to cover amortization of the loan and also a sum representing depreciation over the 30-year period.

It is expected parts of the building can be occupied early in June. All of the shipping facilities and storage and the Bookkeeping and Accounting and General Order Departments are expected to be transferred to this building. While there is no physical connection between the current Headquarters and the Cherry St. property, it is just a few steps across Quarry St. to enter the new property. Better trucking and handling facilities are being made available, and there is considerable additional room for future expansion.

Just what the future may hold for this Headquarters location with the tremendous expansion expected along the old right-of-way of the Pennsylvania Railroad that went into Broad Street Station, no one can foretell, but the officers feel that the rather involved negotiations and operations which took place during the past year protect the Society's future expansion and that the investments should prove to be worthwhile.

Investments.—Investments of Society funds (General, Building, Research, Committee, Medal and Lecture Funds) as of December 11, 1953, are given in the appended auditors' report, both book and market values being shown. As of that date the book value of all investments was $448,814.00, compared with $392,450.47 a year ago; the market value of all investments on December 19, 1953, was $461,679.00.

The following changes in investments during the calendar year 1953 are listed as a matter of record:

GENERAL FUNDS

Sold

Bonds: $2000 U. S. Bonds Defense Series G (matured) converted to U. S. Treasury 3¼%, 1978.

Preferred Stocks: 25 sh. Allis-Chalmers Cum. Conv. 3¼% converted to Common 2 for 1.

Bought	*Cost*
Common Stocks	
25 sh. Aluminum Company	$1 140.96
40 sh. Bethlehem Steel	2 095.99
25 sh. Climax Molybdenum	1 017.38
50 sh. Crown Zellerbach	1 484.79
2 sh. Delaware Light and Power	48.00
30 sh. du Pont	2 899.12
25 sh. General Electric	1 801.50
25 sh. B. F. Goodrich	1 647.31
50 sh. Houston Light and Power	1 244.42
50 sh. International Nickel	2 008.70
57 sh. Pacific Gas and Electric	2 165.63
50 sh. Philadelphia Electric	1 562.95
50 sh. Southern Pacific	2 234.45
40 sh. Standard Oil of New Jersey	2 835.61
40 sh. Texas Company	2 184.35
30 sh. Union Carbide and Carbon	2 030.80
25 sh. Union Pacific	2 719.78
25 sh. Westinghouse Electric	1 153.62
Mutual Funds	
21 sh. Fundamental Investors (Capital Gain)	425.46
5 sh. Broad Street Investing Corp. (Capital Gain)	112.05
45 sh. Eaton & Howard Balanced Funds (Capital Gain)	1 440.90
106.835 sh. Commonwealth Investing Co. (Capital Gain)	717.97
1980.453 sh. Commonwealth Investing Co. (Capital Gain)	20 543.46
Total Common Stock	$32 275.36
Total Mutual Funds	23 239.84
Total	$55 515.20

BULDING FUND

Sold	*Proceeds*
Mutual Funds: 1980.453 sh. Commonwealth Investing Co.	$20 543.46

Bought	*Cost*
Mutual Funds	
77.823 sh. Commonwealth Investing Co. (Dividend Reinvestment)	$543.98
66.225 sh. Commonwealth Investing Co. (Portion of 1953 Depreciation)	500.00
Total	$1 043.98

RESEARCH FUND

Sold	*Profit or Loss (−)*
Preferred Stock	
30 sh. Allis-Chalmers Cum. Conv. 3¼ converted to Common 2 for 1	None

Bought	*Proceeds*
7 sh. Eaton & Howard Balanced Funds	$224.14
6 sh. Broad Street Investing Corp. (Dividend Reinvested)	134.46
Total	$358.60

TEMPLIN FUND

Bought	*Cost*
1 sh. Eaton & Howard Balanced Funds (Dividend Reinvested)	$32.02

TOUR FUND

Bought	*Cost*
1 sh. Eaton & Howard Balanced Funds (Dividence Reinvested)	$32.02

COMMITTEE FUNDS (X-RAY DIFFRACTION)

Bought	*Cost*
$20 000 U. S. Treasury Bonds 2% 1952–54	$19 925.00

1954 Budget:

In the budget for 1954, current income has been placed at $720,500, made up of dues and entrance fees of $232,520; publications sales, $407,500; miscellaneous items, $80,500.

Estimated disbursements are $761,500, made up of publication costs of $285,500; salaries (including Staff expansion and increases in salaries appropriate to meet current conditions), $275,000; and general office expenses, meetings and committees, headquarters, retirement, and miscellaneous, $201,000.

A comparison of estimated income and expenditures shows an indicated deficit of $41,000 for the year. In explanation it should be kept in mind that our fiscal operations must be considered essentially on a three-year basis, and this being the second year since the issuance of the 1952 Book of Standards, our income from sales of publications will probably not approach the very high income of over half a million dollars received in 1953 when heaviest sales of this Book took place.

It is normal procedure to budget a deficit in years corresponding to this one and, while we have been fortunate that none has developed recently, the Finance Committee is prepared for it by its allocation of last year's favorable operating balance to the general surplus to be used if necessary.

Actually, operations for the first four months of the year are very encouraging, and barring any further or more intensive falling off in general business, 1954 may show a better financial result than the budget has anticipated. This continues to reflect a conservative attitude with income estimated somewhat on the low side and disbursements considered quite adequate.

To complete reference to 1954 finances thus far this year, it is noted that during the first four months the following changes in investments have taken place:

GENERAL FUNDS

Bought		*Cost*
*40	sh. Eaton & Howard Balanced Fund	$1 251.60
*85.465	sh. Commonwealth Investment Co.	566.63
30	sh. Atchison, Topeka & Santa Fe	2 961.06
30	sh. Union Carbide and Carbon	2 204.44
50	sh. Sears, Roebuck	3 137.78
50	sh. International Nickel	1 925.00
$15 000	U. S. Treasury 2½%, 1961	15 000.00
Matured		*Received*
$15 000	U. S. Treasury 2%, 1954	14 962.50
5 000	U. S. "G" Bonds	5 000.00

RESEARCH FUND

Bought		*Cost*
	*Eaton & Howard Balanced Fund	187.74
Matured		*Received*
$3 000	U. S. "G" Bonds	3 000.00

TEMPLIN AWARD FUND

Bought		*Cost*
	*Eaton & Howard Balanced Fund	31.29

TOUR AWARD FUND

Bought		*Cost*
	*Eaton & Howard Balanced Fund	31.29

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* Capital Gains Dividend Shares.

Current Investment Policy:

While the Society does not have large sums of money to invest, nevertheless, as the work extends and more new members join and our publication sales become larger, it is natural that the various funds will also increase. The Directors feel that the general surplus, which is barely half of a year's actual disbursements, should be considerably larger, and it is hoped the trend will be in this direction.

The Finance Committee of the Board has devoted much time and effort down through the years on investments, and in the past year the current committee with the Board's approval, has established an Investment Advisory Committee consisting of active members and businessmen in the Philadelphia area to advise the Finance Committee on investment policies and practices. This group feels there should be a definite investment policy; in its recommendations to the Finance Committee the group will implement certain principles already established by the officers. This advisory group does not have authority to act for the Society, but it should afford some relief to the Finance Committee from detailed consideration of investment policies and portfolio.

It will be recalled that about three years ago, in order that our investments might reflect the inflationary trend and to protect the purchasing power of our dollar, rather heavy purchases were made of certain Mutual Funds. This was intended to pass to the operators of these funds responsibilities for investments.

However, with the establishment of the Investment Advisory Committee, the additional purchase of Mutual Funds has been stopped and, although these funds will be held, appreciation from them will come from the dividends received. The new policy envisages direct purchase of various securities. Basic to the investment plan is the decision that at no one time will the Society's holdings in bonds, preferreds, and cash be less than 40 per cent of the total. Conversely, the percentage of equities or common stocks would never exceed 60 per cent.

Concerning the actual investments, the plan eventually to be established would provide that the ratio of equities to fixed investments would decrease with an increase in the securities market, particularly the stock market; and conversely, in a long-trend falling market the plan would call for the purchase of equities. Because of the back history of our investments and current holdings it will take some time to put this police into effect, but in the meantime thert has been a trend, as shown in the lis of investment changes, to the procurement of sound common stocks.

The first quarterly report to the Directors for 1954 shows that in general funds alone (not including various other funds of which the Society is custodian, such as Medal and Award funds, committee funds, etc.) there is a ratio of about 47.3 per cent cash (checking and savings accounts); 14.7 per cent bonds; 5 per cent preferred stocks; and 33 per cent common stocks.

Excluding cash and mutual funds, the investment portfolio of March 31 showed 51.7 per cent common stocks; 6.5 per cent preferreds; and 41.8 per cent bonds.

Investment Status, March 31, 1954:

The market value of all securities in all funds on March 31 was $494,000 compared with the book value of $453,000. The market value of common stocks (owned directly by the Society and not through Mutual Funds) was approximately $180,000 compared with the book value of about $145,000. Considering all securities there is represented about $146,000 of Mutual Funds.

Employee Benefits

Last year the Directors established a Group Life Insurance Plan for the entire Staff with policies of $1000 each in effect. There has also been in operation for a year the Blue Cross Hospitalization Plan, set up on a group basis with the Society underwriting this cost also.

One of the incentives and benefits for the Staff has been participation in the ASTM Retirement Plan established on May 3, 1938. A total of 33 employees now participate. This plan guarantees that on retirement—age 60 for women, 65 for men—the employee will receive a yearly pension of 1 per cent of his highest five years average base salary multiplied by his years of service; the plan excludes any portion of salary in excess of $7000. (This figure was recently raised from $6000 by the Directors to provide those in this range with some additional retirement income.) This plan is independent of Social Security; each employee contributes a percentage of salary to Social Security, in line with the law, and those participating in the Retirement Plan also underwrite a portion of that cost.

Including Social Security, Retirement, and the other benefits, it is expected the total ASTM cost for 1954 will aggregate about $26,000. This is 3.4 per cent of expected operating disbursements, or about 9.5 per cent of the salary budget.

The Directors have been pleased to make these various benefits available to the Staff and to provide incentive for service at Headquarters, and the employees on their part have appreciated the considerations given.

Administrative Matters

Proposed Amendment of By-laws:

Several members and officers suggested to the Directors that the By-laws be revised to provide for a secret election of officers. Previously a secret ballot would have been used only when there was more than one nomination for any given office. The Board of Directors recommends to the Society that the second sentence in Article III, Section 6, of the By-laws dealing with the issuance of an official ballot be changed to read as follows by the deletion of the words in brackets:

> "An official ballot shall be issued to the members between May 25 and June 1, which ballot shall contain names of nominees made according to the provisions of this Article. [In case the official ballot contains more than one nomination for any given office,] The method of voting shall be by secret ballot. The voter shall have the right to substitute any name or names of members of the Society for a corresponding number of names on the ballot."

Previously the By-laws provided that the meeting of the Nominating Committee to select candidates for national officers should be held in March. Frequently, it has been convenient for this group to convene during ASTM Committee Week, but scheduling committee week early in February as was done this year would prevent the Nominating Committee from meeting at that time. Consequently the Directors recommend that the first sentence of Article III, Section 3, of the By-laws be amended as follows by the addition of the words in italics:

> "The meeting of the Nominating Committee shall be held at such time in the month of *February or* March and at such place as shall be determined by the Board of Directors . . . . ."

As required by the revisions in the By-laws, these proposed amendments have already been printed in the notices for the Annual Meeting, and the Board recommends that the Annual Meeting of the Society approve the proposed amendment for submission to letter ballot vote.

Regulations Governing Technical Committees:

The current Regulations Governing Technical Committees define in Article III the terms "standards" and "recommended practices," and in a footnote there is a definition of "specifications" and "methods." In response to a request the Administrative Committee on Standards developed a definition of a "classification," and the Board of Directors has approved this for inclusion in the regulations. At the same time the Board approved the embodiment of the definition of "specifications" and "methods" in the body of the regulations rather than in the footnote.

The definitions as they would appear read as follows:

Classification.—A "Classification" as applied to materials or products may be defined as a systematic arrangement or division into groups based on similar characteristics such as origin, composition, properties, or use.

Specifications.—Specifications are designed to govern the purchase of materials in terms of physical, chemical, or other properties.

Methods.—Methods include sampling and test procedures used in determining the properties that may be specified but not values for these properties.

Society Headquarters:

Details are given in the section of this report dealing with the ASTM Building Fund of the disposal of part of our real estate and the acquisition of a property at the rear of the present Headquarters on Race St. As various departments move into this renovated building, the rather serious crowding and lack of facilities in the Race St. building will be gradually alleviated.

There is no question that the acquisition of the present building in 1945 was a very constructive move whether viewed from the standpoint of cost of operations, location, or efficiency of operations. It is believed the purchase of the additional building on Cherry St. was made at a very reasonable cost and that it will meet the needs of the Staff and provide storage and other facilities for some time to come. Meanwhile the officers will continue to be in close touch with local real estate and development plans. The removal of the so-called "Chinese" wall on Market St., the viaduct over which the Pennsylvania Railroad directed its trains into the old Broad Street Station, will change the complexion of this entire area rather extensively.

Headquarters Staff:

Reference is made in the President's Message at the front of this report to an increase in the Society's Headquarters' Staff. As the number and size of our publications continue to increase, more editorial help is needed, and to handle the increasing volume of publications sales, we must from time to time augment our order, billing, and shipping departments. We have been fortunate in acquiring as needed conscientious help.

While some assignments were made to the current staff of a number of the responsibilities of the Assistant Secretary when he was elected Executive Secretary and Treasurer, yet he continued to carry some phases of this work. Last fall, however, Fred F. Van Atta, formerly with the General Contractors Association, and earlier Acting Secretary-Treasurer of the American Concrete Institute, was appointed Special Assistant reporting directly to the Executive Secretary. He has assumed a number of the responsibilities handled in the office of the Assistant Secretary and also has carried out other special assignments. In general, he is responsible for coordination and extension of our developmental and promotional activities. He has also handled the Exhibit of Testing and Scientific Apparatus and Laboratory Supplies and the Staff responsibilities for the Photographic Exhibit. He reported to ASTM Headquarters officially on September 16. A brief biographical sketch and photograph appeared in the October ASTM BULLETIN.

At the meeting on May 11, the Directors appointed Mr. Van Atta Assistant Secretary.

The Society officers are giving some thought to further additions to the Staff along technical and editorial lines.

Cooperative Activities

In much of our technical and research work, the Society receives the close cooperation of many other organizations and in turn cooperates with other groups where the work is of interest to our technical committees or groups of our members. A list of the Society representatives on other bodies is listed in the ASTM Year Book. It is not feasible here to note all of the cooperative efforts but reference is made to some of these.

The Society is intensely interested in standardization activities of the General Services Administration of the Federal Government, concerned largely with Federal specifications,. and also with the work in the Defense Department where the Departments of the Army, Navy, and Air Force have large groups following standardization activities. Both the civilian and military branches of the Government are well represented on the ASTM technical committees. This has many advantages both to ASTM and the government.

A special committee of the Board of Directors entitled Committee on Government Contacts has from time to time reviewed with various officials in Washington the status of our work. The reorganization of the Defense Department Standards Branch has been of much interest, and contacts have been made with officials of the Office of Assistant Secretaries of Defense, Logistics and Supply, and Engineering Applications. There is a determined effort in the Defense Department to coordinate its wide-flung standards work, and this should have important bearing in stimulating even closer contacts with ASTM and other standards-writing bodies.

The Society has been vitally interested for many years in the work of the National Bureau of Standards, and the fine cooperation between the Bureau and ASTM is an outstanding example of how activities in one organization can complement work in another. There are a large number of members, committee members, and officers of the Society who are from the Bureau, and these men have contributed immeasurably to the advancement of our work. The Society or its committees are sponsoring various investigations at the Bureau, the data from which will be of great importance in our standards work.

At the request of the Bureau the Society has assumed responsibility for the publication of the widely-distributed Directory of Commercial and College Laboratories, the former Bureau publication M187. This lists facilities available in the laboratories and the commodities they are prepared to test. It is expected questionnaires will be distributed to all the laboratories in the next few months, and the publication will be issued in the fall.

There is probably no society that depends more on the technical man and the engineer than does ASTM; and while because of its nature as a technical society it cannot do a great deal to stimulate interest in engineering education, nevertheless in various ways the importance of an adequate supply of engineers has been stressed. As a modest step ASTM contributed to the National Science Teachers Assn. the sum of $300 to support the distribution of 1000 copies of the booklet "Selected Science Teaching Ideas." Other professional and technical groups also cooperated in this project. The ASTM Districts have been urged to participate in local activities intended to stimulate interest in engineering education.

The Society accepted the invitation of the American Association of Textile Chemists and Colorists to participate in the Perkin Centennial in 1956 to commemorate the 100th anniversary of the discovery by Sir William H. Perkin of the first synthetic dye—mauve. The Society specifically will sponsor a symposium on serviceability of dyed material with Committee D-13 on Textile Materials taking the lead. Other technical committees might participate in other portions of the program.

The Society participated in a joint Symposium on Steel Wheels held as part of the 1953 ASME Annual Meeting. A number of members of Committee A-1 on Steel participated in this meeting, which was sponsored by the ASME Railroad Division.

An invitation has been received from the International Union of Testing and Research Laboratories for Materials and Structures (RILEM) to participate in the meeting being held in Trondheim in June, 1954. Since Past-President L. J. Markwardt was to be in Europe at this time attending meetings concerned with timber, he acceded to a suggestion that he represent ASTM as an observer at this RILEM meeting. He is expected to give information to the Directors on the status of this European organization.

American Standards Association:

The Society has continued to cooperate closely with the American Standards Assn., of which it was one of the five founders. The ASTM continues to have sponsorship or joint sponsorship of a number of sectional committees functioning under ASA procedure and is represented on many others. A list of these representatives appears in the ASTM Year Book together with the personnel of the sectional committees where ASTM has sponsorship.

Approximately one third of the some 1200 standards that have been approved by the ASA were developed by ASTM. Over these ASTM has full responsibility for submitting revisions, as they occur from time to time, through the proper ASA procedure for approval. This may be done under the Proprietary Standards Procedure, or by using sectional committees.

The matter of greatest interest which has come about during the year is the formation of a new Standards Board to handle a large number of the submittals which ASTM may send to the ASA. This new Board which will comprise the members of the ASTM Administrative Committee on Standards and two additional members designated by ASA Standards Council will take over all work handled in the past by the Miscellaneous Standards Board. It will not have responsibility for projects sponsored by ASTM which are covered by other ASA groups in specific fields.

The submission of new standards to ASA for approval on the recommendation of ASTM technical committees and keeping these up to date has involved considerable effort and time on the part of the Staff and sometimes the technical committee secretaries. Although the new arrangement may not greatly reduce this time, it will trend in that direction. Furthermore, the ASA is giving consideration to revisions of its procedure on the Existing Standards Method and the Proprietary Standards Procedure so that these may be better understood and have greater utility.

Appointments:

The following appointments were made during the year:

Alexander Gobus, North American Philips Co., Inc., as ASTM representative at the International Institute of Welding meetings in Copenhagen, July, 1953.

W. H. Finkeldey, Singmaster & Breyer, reappointed to the Advisory Committee on Corrosion for a term of three years.

A. F. Tesi, Celanese Corp. of America, as ASTM representative on ASA Sectional Committee on Institutional Textiles.

J. C. Moore, National Paint, Varnish, and Lacquer Association, Inc., and P. J. Smith, ASTM Standards Editor, as ASTM representatives on the Joint Federation-ASTM Committee on Paint, Varnish, Lacquer, the former replacing R. D. Bonney, Congoleum-Nairn, Inc.

L. H. Winkler, Bethlehem Steel Co., Inc., on ASA Mechanical Standards Board, replacing L. B. Jones, deceased.

Myron Park Davis reappointed as the Society's representative on ASA Safety Standards Board.

J. H. Foote, Commonwealth Associates, Inc. reappointed as ASTM representative on ASA Standards Board.

F. L. Marsh, National Gypsum Co., representing Committee C-11 on ASA Sectional Committee A 42 on Specifications for Plastering.

H. M. Smith, Bureau of Mines, Petroleum Experiment Station, on ASA Sectional Committee Z 11 on Petroleum Products and Lubricants, succeeding T. A. Boyd, General Motors Corp.

H. R. Wolf, General Motors Corp., on ASA Sectional Committee Z 26 on Safety Glass, succeeding H. C. Mougey, General Motors Corp.

J. J. Kanter, Crane Co., on Joint Committee on Definitions of Terms Relating to Heat Treatment, succeeding T. S. Fuller, Consultant.

Francis Scofield, National Paint, Varnish, and Lacquer Association, Inc., on Inter-Society Color Council, succeeding W. C. Granville, Container Corp. of America.

W. D. Appel, National Bureau of Standards, as ASTM representative on Committee on AATCC Perkin Centennial.

M. A. Swayze, Lone Star Cement Corp., as ASTM representative at the 50th Anniversary Meeting of the American Concrete Inst. in Denver, February, 1954.

A. W. Tracy, American Brass Co., on Inter-Society Corrosion Committee, succeeding Sam Tour, Sam Tour and Co., Inc.

W. G. Holtz, Bureau of Reclamation, appointed Society representative at International Soils Conference, June, 1953. G. P. Tschebotarioff, Princeton University, also represented ASTM.

Respectfully submitted on behalf of the Board of Directors,

L. C. BEARD, JR.,
President.

R. J. PAINTER,
Executive Secretary.

June, 1954.

APPENDIX I

REPORT OF THE AUDITORS FOR THE FISCAL YEAR JANUARY 1 TO DECEMBER 11, 1953

Philadelphia, January 5, 1954

MR. R. J. PAINTER, *Executive Secretary*
AMERICAN SOCIETY FOR TESTING MATERIALS
Philadelphia, Pa.

Dear Sir:

We have examined the books and accounts of the American Society for Testing Materials for the period ended December 11, 1953, the date the Society closed its books for the year 1953. We did not make a detailed audit of all transactions, but made tests to the extent we considered appropriate in determining the accuracy of the accounts.

Cash on deposit in checking and savings accounts, and cash represented by certificates of deposit were verified by direct correspondence with the various depositories and reconciled with the cash records. Accounts receivable were not verified by correspondence with debtors. The investments owned by the Society, as detailed later in this report were examined by us. Such securities are in safe deposit box of the Society at the Girard Trust Corn Exchange Bank. Income from investments for the period under review was verified by us and found to be properly recorded on the books of the Society.

We have prepared and submit herewith balance sheet as of December 11, 1953, statement of cash receipts and disbursements for the period ended that date, and other supporting schedules which, in our opinion, subject to the foregoing comment, present fairly the financial position of the Society at December 11, 1953, and the results of its operations for the period ended that date.

Respectfully submitted,
JOHN HEINS & CO.

BALANCE SHEET AS OF DECEMBER 11, 1953

(Including Special and Designated Funds)

ASSETS

General Funds:				
Cash		$161 712.48		
Less Check No. 2568 as of December 9, 1953 (drawn against cost of 1953 *Proceedings* and 1953 Supplements to Book of Standards)		60 500.00	$101 212.48	
Investments (Market Value $351 475.21)—Cost			338 008.56	
Accounts Receivable			63 221.97	
Loans Receivable (Building Fund)			87 100.12	
Advance to Forrest Products Laboratory			500.00	
Total Current Assets General Funds			590 043.13	
Furniture and Fixtures (depreciated book value)			22 814.82	
Total Assets General Fund				$612 857.95
Building Fund:				
Cash			63 601.49	
Investments (Market Value $12 905.31)—Cost			13 632.83	
Land (Cost)			30 000.00	
Building and construction costs		156 390.87		
Less Reserve for depreciation		37 150.00	119 240.87	
Land and improvements, 1915–19 Cherry Street, Philadelphia, Pa.			8 549.89	
Land and buildings, 1921–29 Cherry Street and 1924–30 Quarry Street, Philadelphia, Pa.			87 020.29	
Total Assets Building Fund				322 045.37
Other Special and Designated Funds:				
Cash:				
ASTM Research Fund		8 817.58		
Dudley Medal and Marburg Lecture Fund	1 131.01			
Richard L. Templin Award Fund	700.18			
Sam Tour Award Fund	142.99			
Total Medal and Lecture Funds		1 974.18		
Committee Funds		152 536.00	163 327.76	
Investments:				
ASTM Research Fund (Market Value $55 976.45)—Cost		53 995.66		
Dudley Medal and Marburg Lecture Fund, (Market Value $5 067.50)—Cost		6 625.00		
Richard L. Templin Award Fund (Market Value $1 090.60)—Cost		1 057.20		
Sam Tour Award Fund (Market Value $1 620.32)—Cost		1 569.58		
Committee Funds (Market Value $33 543.76)—Cost		33 925.00	97 172.44	
Total Assets, Special and Designated Funds				260 500.20
Total Assets				$1 195 403.52

NOTE.—All market values of securities are as of December 11, 1953.

LIABILITIES

General Funds:			
Advance Collections		$11 550.29	
Accounts Payable:			
Committee C-1		128.23	
Joint Committee on X-ray Diffraction		74 253.15	
Institute of Petroleum		2 775.99	
Pennsylvania Sales Tax Collections		28.75	
Total Current Liabilities General Funds		88 736.41	
Life Membership Fund	$3 812.50		
Publication Fund	16 841.80		
Book of Standards Reserve	60 400.18		
Executive Retirement Reserve	14 873.60		
Retirement Fund Reserve	24 097.43		
Reserve for Depreciation of Investments	20 000.00		
Reserve for Additional Cost of Replacement of Headquarters Building	25 000.00		
Special Annual Meeting Entertainment Account	7 586.64		
Exhibit Annual Meeting	1 355.00		
Warwick Memorial	1 550.00	175 517.15	
Surplus		264 253.56	
		348 604.39	
Total Liabilities and Surplus General Funds			$612 857.95
Building Fund:			
Contributions from Members		173 722.35	
Contributions from ASTM General Funds		47 989.57	
Notes Payable General Funds		87 100.12	
Accumulated Income, Profit on Investments		13 233.33	
Total Building Fund			322 045.37
Other Special and Designated Funds:			
ASTM Research Fund:			
Principal	57 030.05		
Income	5 783.19	62 813.24	
Dudley Medal and Marburg Lecture Fund:			
Principal	6 625.00		
Income	1 131.01	7 756.01	
Richard L. Templin Award Fund:			
Principal	1 669.14		
Income	88.24	1 757.38	
Sam Tour Award Fund:			
Principal	1 569.58		
Income	142.99	1 712.57	
Committee Funds, Unexpended Balance		186 461.00	
Total Special and Designated Funds			260 500.20
Total Liabilities and Funds			$1 195 403.52

COMPARISON OF GENERAL FUNDS FOR FISCAL YEARS 1949–1953 INCLUSIVE.

At Close of Fiscal Year	Assets				Liabilities			
	Cash	Investments	Accounts Receivable	Furniture and Fixtures	Accounts Payable	Reserve for Book of Standards	Miscellaneous Funds	Surplus
1949	$56 379.22	$192 325.57	$36 382.87	$18 078.39	$12 349.77	$40 000.00	$31 580.92	$219 235.36
1950	147 957.36	222 662.96	50 692.18	17 959.00	59 919.59	61 900.18	65 973.89	251 477.84
1951	164 497.75	263 995.13	77 239.16	18 758.61	72 990.86	101 900.18	90 536 48	259 063.13
1952	200 537.56	282 493.36	63 050.85	22 475.95	86 506.97	101 900.18	114 326.31	265 824.26
1953	101 212.48	338 008.56	150 822.09	22 814.82	88 136.41	60 400.18	115 116.97	348 604.39

COMMITTEE FUNDS

Committee A-1 On Steel	$2 548.99
Committee A-5 On Corrosion of Iron and Steel	1 134.85
Committee B-3 On Corrosion of Non-Ferrous Metals and Alloys	2 599.83
Committee B-6 On Die Cast Metals and Alloys	2 762.56
Committee B-8 On Electrodeposited Metallic Castings	11.25
Committee C-1 On Cement	1 673.67
Committee C-1 Cement Reference Laboratory	640.95
Committee C-9 Sanford E. Thompson Medal Fund	990.42
Committee C-9 On Concrete and Concrete Aggregates	154.17
Committee C-15 On Manufactured Masonry Units	414.33
Committee C-16 On Effect of Moisture in the Performance of Thermal Insulation	995.00
Committee C-18 On Natural Building Stones and Slate	386.58
Committee D-1 On Paint, Varnish, Lacquer and Related Products	697.71
Committee D-2 On Petroleum Products and Lubricants	556.61
Committee D-2 ASTM-IBM	913.79
Committee D-2 D.C.C Reference Fuel Account	23 255.57
Committee D-2 D.C.C National Exchange Group	1 013.52
Committee D-2 D.C.C Equipment Development Project	848.70
Committee D-4 On Road and Paving Materials	6.95
Committee D-5 On Coal and Coke	198.06
Committee D-7 On Wood	28.50
Committee D-7 Pole Research Fund	18 583.21
Committee D-9 On Electrical Insulation Materials	2 433.08
Committee D-10 On Shipping Containers	5.99
Committee D-11 On Rubber and Rubberlike Materials	81.75
Committee D-12 On Soaps and Detergents	633.94
Committee D-13 On Textile Materials	1 350.34
Committee D-15 On Engine Antifreezes	43.00
Committee E-3 On Chemical Analysis of Metals	141.54
Committee E-9 On Fatigue of Metals	209.31
ASA Sectional Committee on Specifications for Cast Iron Pipe	1 423.40
Cleveland District Council	617.59
Detroit District Council	3 006.48
Ohio Valley District Council	4.50
Philadelphia District Council	514.83
Philadelphia District Special (Annual Meeting Account)	792.42
Southern California District Council	129.20
Pittsburgh District Council	665.95
Western New York—Ontario District Council	230.72
Advisory Committee on Corrosion	67 912.14
Administrative Committee on Ultimate Consumer Goods	213.30
Joint Committee on X-ray Diffraction, chemical analysis	37 952.57
Joint Committee on X-ray Diffraction, research associates	342.63
Joint Committee on X-ray Diffraction, IBM calculator	8 623.00
	186 461.00

Accounted for as follows:		
Cash in bank and on hand	$152 536.00	
Investments (at cost)	33 925.00	$186 461.00

DUDLEY MEDAL AND MARBURG LECTURE FUND

Balance, December 19, 1952:			
Principal—Investments (at cost)	$6 625.00		
Income—Cash	1 419.91	$8 044.91	
Receipts—Interest on investments		264.00	$8 308.91
Disbursements:			
Honorarium		400.00	
Dudley Medal		77.00	
Miscellaneous (travel expense, etc.)		75.90	552.90
Balance, December 11, 1953:			7 756.01
Accounted for as follows:			
Principal—Investments (at cost)		6 625.00	
Income—Cash in bank		1 131.01	$7 756.01

RICHARD L. TEMPLIN AWARD FUND

	Total	*Invested*	*Uninvested Cash*
Principal Account:			
Balance, December 19, 1952	$1 037.12	$1 025.18	$11.94
Receipts:			
Transfer from income—stock dividend	32.02	32.02	
Donation of R. L. Templin	600.00		600.00
	$1 669.14	$1 057.20	$611.94
Income Account:			
Balance, December 19, 1952		$71.12	
Receipts—Interest and dividends on investments		79.14	$150.26
Disbursements:			
Transfer to principal account		32.02	
Templin Awards		25.00	
Engrossing certificates		5.00	62.02
Balance, December 11, 1953			$88.24

SAM TOUR AWARD FUND

	Total	*Invested*	*Uninvested Cash*
Principal Account:			
Balance, December 19, 1952	$1 537.56	$1 537.56	0
Receipts—Transfer from income account	32.02	32.02	
	$1 569.58	$1 569.58	0
Income Account:			
Balance, December 19, 1952		$109.00	
Receipts—Interest and dividends on investments		102.26	$211.26
Disbursements:			
Transfer to principal account		32.02	
Award		35.00	
Engrossing certificate		1.25	68.27
Balance, December 11, 1953			$142.99

ASTM RESEARCH FUND

	Total	*Invested*	*Uninvested Cash*
Principal Account:			
Balance, December 19, 1952	$53 671.45	$53 637.06	$34.39
Receipts—Stock dividends transferred from income	358.60	358.60	
Contribution from General Fund	3 000.00		3 000.00
	$57 030.05	$53.995.66	$3 034.39
Income Account:			
Balance, December 19, 1952		$5 650.97	
Receipts—Interest and dividends on investments		2 582.00	$8 232.97
Disbursements:			
Transfers to principal account		358.60	
Printing, etc.		2 091.18	2 449.78
Balance, December 11, 1953			$5 783.19

RECEIPTS AND DISBURSEMENTS

FOR THE PERIOD DECEMBER 19, 1952 TO DECEMBER 11, 1953

Cash balance, December 19, 1952			$200 537.56
RECEIPTS			
Operating Receipts (Budgeted):			
Dues and Entrance Fees:			
Current Dues	$222 196.84		
Past Dues	1 399.17		
Advance Dues	4 454.00		
Income, Life Membership Fund	175.00		
Entrance Fees	5 480.00		
Total Dues		$233 705.01	
Sales of Publications:			
Book of Standards (Members, additional parts)	54 177.00		
1949 Book of Standards	1 248.00		
1952 Book of Standards	233 240.09		
1950 Supplements to Book of Standards	833.60		
1951 Supplements to Book of Standards	1 329.15		
1953 Supplements to Book of Standards	370.25		
Methods of Chemical Analysis of Metals	3 840.45		
Compilation of Standards	78 902.87		
Separate Standards	27 761.63		
Selected Standards for Students	4 188.90		
Proceedings	6 356.05		
50 Year Index and Papers	4 227.70		
Spring Meeting Papers	54.35		
BULLETIN Subscriptions (nonmembers)	3 115.07		
Special and Miscellaneous Publications	92 616.79		
Total Sales of Publications		512 261.90	
Miscellaneous:			
Advertising—BULLETIN	26 878.13		
Advertising—Index	1 520.00		
Interest and Dividends	21 955.79		
Registration and Other Fees—Meetings	13 767.50		
ASTM Exhibit at Annual Meeting	1 355.00		
Staff Services	2 733.53		
Miscellaneous	462.76		
Total Miscellaneous Items		68 672.71	
Total Operating Receipts (Budgeted)		814 639.62	
Nonoperating Receipts (Not Budgeted):			
Excess Remittance	2 568.95		
Committee C-1 for Technical Assistant	2 640.00		
Retirement Fund Reserve	54.66		
Joint AIME-ASTM Publication Fund	136.50		
Sale of X-ray Diffraction Cards	53 196.30		
British and IP Metric Tables	1 552.06		
Institute of Petroleum Publications	134.02		
From Building Fund on Account of Loan	36 000.00		
Annual Meeting Luncheons	925.75		
Buffet Supper	258.75		
Gillett Memorial	430.00		
Total Nonoperating Receipts		97 896.99	
Total Receipts			912 536.61
Total Receipts for 1953 and Cash Balance, December 19, 1952			$1 113 074.17

DISBURSEMENTS

Operating Disbursements (Budgeted):			
Publications:			
Year Book	$12 614.54		
1949 Book of Standards (net refund)	2.81		
1952 Book of Standards	9 670.46		
1953 Supplements to Book of Standards	35 706.91		
Emergency Standards	1 090.00		
Methods Chemical Analysis Metals	64.55		
Compilation of Standards	27 944.66		
Separate Standards	11 941.58		
1951 Proceedings	424.50		
1952 Proceedings (net refund)	1 599.15		
1953 Proceedings	37 677.23[a]		
Preprints	8 725.21		
ASTM BULLETIN	32 031.07		
Circulars to members	2 577.81		
50 Year Index to Papers	232.58		
Index to Standards	9 618.65		
Special and Miscellaneous Publications	75 093.33		
Total Disbursements—Publications		$263 811.12	
Salaries	237 761.19		
General Office Expenses	75 773.31		
Expenses—Technical and District Committees	9 978.66		
Expenses—Meetings	13 274.34		
Headquarters Occupancy Expense (includes $5 700 depreciation on building)	21 657.63		
American Standards Association	1 500.00		
Traveling Expense, Administrative and Special Committees	7 167.41		
Furniture and Fixtures	3 598.13		
Principal ASTM Research Fund	3 000.00		
Dues, Contributions, Miscellaneous	1 281.09		
Legal Services	1 250.00		
Group Insurance	518.50		
Employees' Retirement Fund	17 439.80		
Federal Old Age Survivors	2 678.57		
Blue Cross	433.20	397 311.83	
Total Operating Disbursements (Budgeted)		661 122.95	
Nonoperating Disbursements (Not Budgeted):			
Refund of Excess Remittances	2 574.95		
Investments	55 515.20		
Book of Standards Reserve	101 500.00		
Technical Assistant Committee C-1	2 654.40		
Transfer to Joint Committee on X-ray Diffraction	47 500.00		
Cost and Refunds on X-ray Diffraction Cards	6 462.51		
Institute of Petroleum Publications	496.28		
Annual Meeting Luncheon	1 069.50		
Executive Retirement Reserve	1 119.00		
Gillett Memorial Fund	401.25		
Contribution to Building Fund	32 000.00		
Loan to Building Fund	87 100.12		
Buffet Supper	338.50		
Transfer to Committee D-7	5 000.00		
Transfer to Philadelphia District Entertainment	1 000.00		
Gift to Widow of Executive Secretary	6 000.00		
Miscellaneous	7.03		
Total Nonoperating Disbursements		350 738.74	
Total Disbursements			1 011 861.69
Cash Balance, December 11, 1953			$101 212.48

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[a] These accounts include $60 500 representing a check drawn against cost of 1953 Proceedings and 1953 Book of Standards, but not actually paid on December 11, 1953.

ASTM BUILDING FUND

DETAILS OF ASTM BUILDING FUND CASH RECEIPTS AND DISBURSEMENTS FOR THE PERIOD DECEMBER 19, 1952 TO DECEMBER 11, 1953

Cash balance, December 19, 1952		$1 719.29
Receipts		
Contributions from Members	$2 094.55	
Interest and Dividends on Investments	847.92	
Receipt on Account of Appraisal Costs	100.00	
Proceeds Sale of 59/80 of 1915–1919 Cherry Street	34 667.71	
From ASTM General Fund:		
On Account of Depreciation on Building, Elevator, and Air Conditioning Installation	5 700.00	
On Account of Interest and Amortization of Note	37 020.00	
On Account of Securities Sold	20 543.46	
Loan on Account of Purchase of Building	87 100.12	188 073.76
		189 793.05
Disbursements		
Purchase of 144.048 shares Commonwealth Investment Co.	$1 043.98	
Purchase of property 1921–1929 Cherry Street and 1924–1930 Quarry Street	87 020.29	
Taxes on Cherry Street Property	658.84	
Cost of Appraisal	250.00	
Architect's Fee	198.45	
Interest on Loan from ASTM General Fund	1 020.00	
Reduction of Loan from ASTM General Fund	36 000.00	126 191.56
Cash balance, December 11, 1953		$63 601.49

ASTM BUILDING FUND

DETAILS OF ASSETS AND LIABILITIES OF BUILDING FUND AS OF DECEMBER 11, 1953

Assets

Cash in Girard Trust Corn Exchange Bank, Philadelphia, Pa.				$63 601.49
Investments: (Market value $12 905.31)				
$8 500 U. S. Treasury bonds 2½s 1967–72			$8 632.83	
5 000 U. S. Savings bonds series "G" 2½s			5 000.00	13 632.83
Property 1916–18 Race Street, Philadelphia, Pa:				
Purchase Price	$53 625.00			
Commission to Agent	2 681.25			
Settlement Fee, net	197.10			
	$56 503.35			
Allocated to:				
Land			30 000.00	
Building		$26 503.35		
Construction	$131 040.44			
Less Proceeds from Sales and Salvage of Equipment and Rentals	1 152.92	129 887.52		
		156 390.87		
Reserve for Depreciation (provided from General Funds)		37 150.00	119 240.87	
			149 240.87	
Property 1915–1919 Cherry Street, Philadelphia, Pa:				
Purchase Price	$27 500.00			
Commission to Agent	1 375.00			
Settlement Fee, net	303.61			
	29 178.61			
Sold 59/80ths of above property	21 519.19			
Balance of cost		7 659.42		
Improvements		890.47	8 549.89	
Property 1921–1929 Cherry Street and 1924–1930 Quarry Street, Philadelphia, Pa:				
Purchase price	$81 500.00			
Commission to Agent	4 075.00			
Settlement Fee, net	1 525.12			
	$87 100.12			
Allocated to:				
Land		38 500.00		
Building	$48 600.12			
Less, Rentals	79.83	48 520.29	87 020.29	244 811.05
Total Assets				322 045.37

Liabilities and Funds

Contributions from Members			$173 722.35	
Contributions from ASTM Funds			47 989.57	
Accumulated Income:				
Interest and Dividends on Investments		$5 205.68		
Profit on Disposal of Securities, net		76.27		
Profit on Sale of 59/80 1915–1919 Cherry Street		13 148.52		
		18 430.47		
Less Interest on Loan from General Fund	$4 010.96			
Real Estate Taxes on Cherry Street	1 036.18			
Appraisal	150.00	5 197.14	13 233.33	
Loan payable to ASTM General Funds			87 100.12	$322 045.37

INVESTMENTS

AS OF DECEMBER 11, 1953

GENERAL FUNDS

Par Value	Bonds	Cost or Book Value	Market Value[a]
$4 000	Erie R. R. Co. Gen. Conv. Income "A" 4½s 1/1/2015	$2 832.00	$2 960.00
35 600	U. S. Savings Bonds Series "G" 2½s	35 600.00	34 148.20
5 000	Walworth Co. 3¼s Conv. Deb. 5/1/76	5 496.53	3 350.00
2 000	U. S. Treasury 3¼s 6/15/83–78	2 000.00	2 100.00
15 000	U. S. Treasury 2¼s 6/15/55–52	15 004.69	15 070.31
15 000	U. S. Treasury 2s 12/15/54–52	14 943.75	15 037.50
15 000	U. S. Treasury 2s 6/15/54–52	14 962.50	15 046.88
		$90 839.47	$87 712.89
Shares	*Preferred Stocks*		
67	American Airlines, Inc. 3½s Cum. Conv.	$5 911.55	$4 807.25
50	Chicago, Rock Island & Pacific R. R. Co. 5s "A" Cum. Conv.	4 434.60	4 650.00
50	Food Machinery and Chemical Co. 3¼s Cum. Conv.	4 750.10	4 325.00
60	Jones & Laughlin Steel Corp. 5% Cum. "A"	5 386.73	5 130.00
		$20 482.98	$18 912.25
	Common Stocks		
150	Allis-Chalmers Mfg. Co., no par value	$6 391.35	$6 675.00
100	American Rad. & Std. Sanitary Corp.	1 564.32	1 350.00
25	American Telephone & Telegraph Co.	3 798.72	3 906.25
100	American Tobacco Co.	7 370.97	6 300.00
60	American Viscose Corp.	2 323.58	2 122.50
100	American Cyanamid Co.	3 669.14	4 812.50
125	Aluminum Co. of America	4 820.70	7 562.50
40	Bethlehem Steel Co.	2 095.99	2 065.00
115	Carpenter Steel Co.	6 104.75	4 786.88
100	Chase National Bank	3 412.50	4 550.00
25	Climax Molybdenum	1 017.38	968.75
1	Consumer Power	37.00	39.88
50	Crown Zellerbach Corp.	1 484.79	1 756.25
17	Delaware Power & Light Co.	283.00	469.63
160	Dow Chemical Co.	3 944.32	5 920.00
30	E. I. du Pont de Nemours & Co.	2 899.12	3 157.50
25	General Electric Co.	1 801.50	2 178.13
100	General Telephone Corp.	3 312.82	4 475.00
25	B. F. Goodrich	1 647.31	1 937.50
216	Gulf Oil Corp.	6 273.27	9 693.00
50	Houston Lighting & Power Co.	1 244.42	1 437.50
200	International Harvester Co.	6 406.67	5 525.00
50	International Nickel Co. of Canada	2 008.70	1 775.00
200	Lone Star Cement Co.	4 941.44	6 000.00
45	Montgomery, Ward & Co.	2 646.41	2 525.63
3	Niagara Mohawk Power Co.	83.82	83.63
100	Ohio Oil Co.	2 623.35	5 587.50
57	Pacific Gas & Electric Co.	2 165.63	2 237.25
250	Philadelphia Electric Co.	5 915.67	7 968.75
125	Public Service Electric & Gas Co.	4 558.50	3 218.75
50	Republic Steel Corp.	2 152.93	2 418.75
100	Socony-Vacuum Oil Co.	2 510.28	3 512.50
50	Southern Pacific Co.	2 234.45	1 831.25
40	Standard Oil Co. of New Jersey	2 835.61	2 915.00
40	Texas Co.	2 184.35	2 255.00
30	Union Carbide and Carbon Co.	2 030.80	2 182.50
25	Union Pacific Railroad Co.	2 719.78	2 725.00
30	United Gas Improvement Co.	446.68	997.50
25	Westinghouse Electric Corp.	1 153.62	1 256.25
		$115 115.64	$131 179.03

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[a] **Market values were taken from current financial publications as of close of market December 11, 1953.**

Par Value	*Mutual Funds* (Bid only)	*Cost or Book Value*	*Market Value*[a]
271	Broad Street Investing Co.	$5 375.04	$5 853.60
3 531.288	Commonwealth Investing Co.	24 814.42	23 412.44
2 091	Eaton & Howard Balanced Fund	63 111.67	65 155.56
1 011	Fundamental Investors, Inc.	18 269.34	19 249.44
		$111 570.47	$113 671.04

ASTM BUILDING FUND

Par Value	*Bonds*		
$8 500	U. S. Treasury 2½s 6/15/72–67	$8 632.83	$8 165.31
5 000	U. S. Savings Bonds series "G" 2½s	5 000.00	4 740.00
		$13 632.83	$12 905.31

ASTM RESEARCH FUND

Par Value	*Bonds*		
$1 500	B. &. O. R. R. Ref. & Gen. 5s series "M" 3/1/96	$1 511.25	$1 151.25
9 900	U. S. Defense Savings Bonds series "G" 2½s	9 900.00	9 562.80
2 000	U. S. Treasury 2½s 3/15/70–65	2 000.00	1 938.75
		$13 411.25	$12 652.80

Shares	*Preferred Stocks*		
33	American Airlines, Inc. 3½s Cum. Conv.	$3 366.00	$2 367.75

Shares	*Common Stocks*		
160	Allis-Chalmers—no par value	$7 428.81	$7 120.00
196	General Motors Corp.—Gift[b]	6 504.75	11 539.50
100	Jones & Laughlin Steel Corp.	2 636.06	2 025.00
55	Montgomery, Ward & Co.	3 151.63	3 086.88
		$19 721.25	$23 771.38

Shares	*Mutual Funds*		
295	Broad Street Investing Corp	$5 962.83	$6 372.00
347	Eaton and Howard Balanced Fund	11 534.33	10 812.52
		$17 497.16	$17 184.52

DUDLEY MEDAL AND MARBURG LECTURE FUND

Par Value	*Bonds*		
$500	B. & O. R. R. Ref. & Gen. Mtg. 6s series "J" 12/1/95	$550.00	$447.50
6 000	B. & O. R. R. Ref. & Gen. Mtg. 5s series "G" 12/1/95	6 075.00	4 620.00
		$6 625.00	$5 067.50

RICHARD L. TEMPLIN AWARD FUND

Shares			
35	Eaton and Howard Balanced Fund	$1 057.20	$1 090.60

SAM TOUR AWARD FUND

Shares			
52	Eaton and Howard Balanced Fund	$1 569.58	$1 620.32

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[b] The income from these shares is, by agreement, paid to an annuitant.

COMMITTEE FUNDS

Par Value		*Cost or Book Value*	*Market Value*
$1 000	U. S. Treasury Bonds 2⅞s 3/15/60–55	$1 000.00	$1 020.63
2 000	U. S. Treasury Bonds 2½s 12/15/69–64	2 000.00	1 945.00
3 000	U. S. Treasury Bonds 2½s 3/15/70–65	3 000.00	2 908.13
3 000	U. S. Treasury Bonds 2½s 12/15/72–67	3 000.00	2 880.00
5 000	U. S. Treasury Bonds series "G" 2½s dated 1/1/50	5 000.00	4 740.00

X-RAY DIFFRACTION COMMITTEE

Par Value			
20 000	U. S. Treasury Bonds 2s 12/15/54–52	19 925.00	20 050.00
		$33 925.00	$33 543.76

APPENDIX II

REPORT OF ADMINISTRATIVE COMMITTEE ON STANDARDS

While the principal function of the Administrative Committee on Standards is, perhaps, generally thought to be that of passing upon recommendations from the technical committees with respect to new tentatives and revisions in the interim between Annual Meetings, its function is the broad one of supervising the standardization work of the Society in general. Several of these functions are indicated by and discussed under the subdivision headings of this report and include, for example, the consideration of the expansion of standardization activities and relations with other standardizing groups, specifically the American Standards Association and the standards organizations of other countries. The review of recommendations from technical committees, however, continues to be a most important function, as a reference to the annual reports of the technical committees will indicate. Most of the annual reports refer to recommendations that have been submitted to the Standards Committee during the year. These actions include 74 new tentatives, revisions of 19 tentatives, tentative revisions of 21 standards, 1 standard reverted to tentative, 5 standards and tentatives withdrawn, and 14 emergency alternate provisions withdrawn. A large number of these recommendations were acted upon at a meeting held on September 9, 1953; the remainder were handled by correspondence. A further meeting of the committee is planned for April 18.

Actions at 1953 Annual Meeting:

As a matter of record, the actions taken at the 1953 Annual Meeting with respect to standards and tentatives are tabulated below:

Existing Tentatives Adopted as Standard	62
Standards Revised	54
New Tentatives	62
Standards Revised and Reverted to Tentative	5
Tentative Revisions of Standards	28
Tentatives Revised	99
Standards and Tentatives Withdrawn	9

Form of Standards:

The improvement of quality and form of standards continues to be an important consideration of the committee. Editorial committees have been organized by a number of the technical committees, and the Standards Committee would wish to see this practice extended. Manuals covering the form of ASTM methods and specifications are in preparation which should be of considerable assistance to committees in this connection. These will also include some discussion of the objectives to be attained and of the general policies with respect to the writing of specifications and methods of test.

EXPANSION OF STANDARDIZATION ACTIVITIES

Of the projects referred to in the report of a year ago, organization has now been effected of the Joint Committee on Soil Conditioners, set up under the joint auspices of the ASTM and the Association of Official Agricultural Chemists. The interest of ASTM is primarily in the evaluation of these conditioners, whereas the AOAC is interested in identification tests. The committee is functioning under temporary officers with W. P. Martin of Ohio State University as temporary chairman, W. A. Raney of Mississippi State College as temporary vice-chairman, and H. N. Stevens of B. F. Goodrich Chemical Co. as temporary secretary.

For the most part, the personnel of the committee is made up of individuals selected because of their interest in conditioners, but in view of the joint nature of the committee there will be three official representatives from both the AOAC and ASTM on the Executive Committee.

Gasket Materials.—The Administrative Committee on Standards still has under consideration the question of the expansion of the Society's work on gaskets. A number of nonmetallic materials are now covered in the standards prepared under Committee D-11 on Rubber and Rubber-like Materials, some of the work having originated in the Joint Technical Committee (with SAE) on Automotive Rubber. In view of the current interest in metallic gasketing materials as well as the various combinations, there is some feeling that the work should be established in a separate committee, and this question is being explored, although generally it has been the policy to look to existing committees in the assignment of new work whenever this is practical.

Coated Fabrics.—In view of a proposal that a project be undertaken in the American Standards Assn. on plastic-coated fabrics, an inquiry to ASTM Committee D-20 on Plastics resulted in a general conference of the several ASTM committees interested in coated fabrics, including Committee D-1 on Paint, Varnish, Lacquer, and Related Products; D-9 on Electrical Insulating Materials; D-11 on Rubber and Rubber-like Materials; D-13 on Textile Materials; and Committee D-20. This conference resulted in the recommendation that the work in this field be concentrated in Committee D-11, since that committee already had work in progress on fabrics coated with rubber and similar materials. The other committees will have representation on the appropriate subcommittee of Committee D-11, and the committee will look to these other committees for standards covering the basic materials, as for example, Committee D-13 for textiles, Committee D-20 for plastic coating materials, Committee D-1 for certain other types of impregnated materials. Committee D-9 will be responsible for any electrical tests.

Reinforced Plastics and Plastic Pipe.—The Standards Committee has been interested in the extension of work taking place in Committee D-20 on Plastics. In view of a number of inquiries received with respect to plastic pipe and particularly in view of the need expressed by the ASA Chemical Industry Advisory Board for standards covering plastic pipe and reinforced plastics, Committee D-20 has reorganized its work on specifications; in place of a single Subcommittee VI on Specifications, the following subcommittees will be organized:

Subcommittee XV on Thermoplastic Materials.
Subcommittee XVI on Thermosetting Materials.
Subcommittee XVII on Plastic Pipe and Fittings.
Subcommittee XVIII on Reinforced Plastics.
Subcommittee XIX on Plastic Films and Sheeting.

It is proposed to organize Subcommittee XVII on Plastic Pipe and Fittings as a joint committee with the Society of the Plastics Industry and to have representation on this committee, as well as on the reinforced plastics subcommittee, of a number of other organizations interested in these fields.

Water Repellent Solutions.—Reference was made in the report of a year ago to the proposal that the Society undertake work on water repellent solutions for masonry surfaces. This work has been assumed by Committee C-15 on Manufactured Masonry Units, and the scope of the committee is being extended accordingly.

Bituminous Flooring Emulsions.—Inquiry is being made of Committee D-4 on Road and Paving Materials and Committee D-8 on Bituminous Waterproofing and Roofing Materials with respect to a proposal that the Society undertake work on bituminous flooring emulsions.

Walkway Surfaces.—Considerable emphasis has been placed recently on the need for measuring the slipperiness or nonskid characteristics of walkway surfaces. While this subject is of rather a general nature and applies with respect to a number of materials, much attention is given to the wax treatment of floors. The Society's Committee D-21 on Wax Polishes and Related Materials has been at work on the development of suitable test procedures so far as waxes are concerned. Work on the evaluation of floor finishes is accordingly being concentrated in that committee, and if satisfactory test procedures are developed applicable in the case of waxes, these may lend themselves as general test procedures. Two methods have been published as information in the ASTM BULLETIN.

Other Pending Proposals.—At various times, inquiries have been received and proposals have been submitted with respect to the Society undertaking work in the field of ore sampling, surface chemistry, abrasives, ion exchange, heavy chemicals, and caulking compounds.

Cooperative Relations.—To an ever increasing extent there is interlocking of interest among the technical committees, particularly in the nonmetallics field. This would be indicated from the disposition of some of the items referred to above. Frequently the common interest is taken care of by cross representation between the committees and sometimes with joint jurisdiction over standards. Occasionally a joint committee may be indicated, but wherever possible the primary jurisdiction is given to one of the existing technical committees with representation from the others concerned. Special coordinating committees may need to be set up in certain areas.

RELATIONS WITH AMERICAN STANDARDS ASSOCIATION

Two methods under the procedure of the American Standards Association are used by ASTM in submitting recommendations to the ASA. One is a combination of the so-called existing standards procedure and the proprietary sponsorship procedure. On the initial reference of an existing ASTM standard to the ASA, it is submitted under the existing standards procedure with a supporting statement giving a history of the development of the standard and indicating the degree of its acceptance. If the standard is approved as American Standard, the ASTM is granted proprietary sponsorship so far as any future revisions are concerned, and such revisions are brought to the attention of the ASA currently for approval under this proprietary sponsorship procedure.

The second method consists of having standards reviewed in a sectional committee made up of representatives of a number of interested organizations but with ASTM as sponsor or cosponsor for the sectional committee.

Standards Submitted Under the Existing Standards Procedure:

The following standards were submitted to the American Standards Assn. for approval as American Standard under the existing standards procedure: 3 standards dealing with nickel, nickel-copper, and nickel-chromium-iron pipe and tubing (B 161, B 165, and B 167); 5 dealing with manufactured masonry units (C 32, C 43, C 126, C 159, and C 279); 1 dealing with clay pipe (C 211); 1 dealing with aggregates for use in interior plaster (C 35); 1 dealing with gypsum partition tile or block (C 52); 4 dealing with gaseous fuels (D 1136, D 1137, D 1142, and D 1145); Specifications for ASTM Thermometers (E 1); and 3 hardness conversion tables (E 33, E 48, and E 93).

Revised Standards Submitted Under the Proprietary Procedure:

In view of the Society having been designated as proprietary sponsor for the revisions of ASTM Standards that had been approved as American Standard under the existing standards procedure, it has submitted to the American Standards Assn. during the year revisions of the Specifications for Drain Tile (C 4); revisions of 3 standards relating to pigments (D 126, D 305, and D 475); 1 relating to soap (D 455); and 2 relating to vulcanized rubber (D 572 and D 573).

Standards Submitted Under Sectional Committee Procedure:

During the year, the following seven sectional committees, for which the Society is sponsor or cosponsor, took action to present recommendations to the ASA as follows:

Sectional Committee A1 on Hydraulic Cements.—This committee has recommended the approval as American Standard of 1 ASTM method, and the approval of revisions of 10 American Standards.

Sectional Committee A37 on Road and Paving Materials.—This committee has recommended the approval of revisions of 11 American Standards.

Sectional Committee A88 on Magnesium Oxychloride Cement Flooring.—This committee has recommended the approval as American Standard of 17 ASTM standards.

Sectional Committee C7 on Bare Electrical Conductors.—This committee has recommended the approval as American Standard of 1 ASTM method, and the approval of revisions of 13 American Standards.

Sectional Committee C59 on Electrical Insulating Materials.—This committee has recommended the approval of revisions of 6 American Standards.

Sectional Committee L14 on Textile Test Methods.—This committee has recommended the approval of revisions of 6 American Standards, and the withdrawal of 3 American Standards.

Sectional Committee Z11 on Petroleum Products and Lubricants.—This committee has recommended the approval as American Standard of 6 ASTM standards, the approval of revisions of 14 American Standards, the withdrawal of 1 American Standard, and the reaffirmation of 10 American Standards.

All of these reports have been referred to the American Standards Assn. Action is still pending so far as the recommendations of Sectional Committee L14 are concerned; the others have been approved.

In addition to these the following sectional committee, functioning directly under the sponsorship of the ASA Electrical Standards Board, has submitted recommendations for consideration by the ASA:

Sectional Committee C8 on Insulated Wires and Cables (Other than Telephone and Telegraph).—This committee has recommended the approval as American Standard of 12 ASTM standards, and the approval of revisions of 1 American Standard.

New ASA Reviewing Body for ASTM Recommendations:

Under the ASA procedure a number of committees have been set up in specific fields to act for the Standards Council on recommendations in these fields. For example, there is an Electrical Standards Board, Construction Standards Board, Mechanical Standards Board, etc. Many of the Society's recommendations have been cleared in the Miscellaneous Standards Board. Discussions in the American Standards Assn. looking toward facilitating the action on standards recommendations, particularly those submitted under the existing standards procedure, under which many ASTM standards are presented to the ASA, led to the proposal that the members of the ASTM Administrative Committee on Standards, might be recognized by the ASA as a reviewing body under its procedure. The Standards Committee members are familiar with the recommendations submitted since it has already approved their reference to the ASA. The ASA is accordingly planning to set up a new reviewing group comprising the members of the ASTM Administrative Committee on Standards and two additional members designated by the ASA to consider and act on all ASTM recommendations formerly under the jurisdiction of the Miscellaneous Standards Board. This proposal has the approval of the ASTM Board of Directors and will shortly be put into effect.

INTERNATIONAL RELATIONS

The Society continues to receive from other countries standards with the request for comment. ASTM committees review these standards and frequently suggestions result. Apart from such informal cooperation, however, quite a number of proposals have been received through the American Standards Association concerning projects that have been proposed under the International Organization for Standardization (ISO) as follows:

Textiles.—Great Britain holds the general secretariat for ISO/TC 38 on Textiles but America holds the secretariat for several subcommittees. American participation in this work of ISO/TC 38 is being handled by a special committee organized in the American Standards Assn. under the sponsorship of ASTM and the American Association of Textile Chemists and Colorists, with representation from the various groups interested. This special committee has been given the designation "L23."

Meetings of the subcommittees on colorfastness and on shrinkage of fabrics in washing are scheduled early in June, 1954, in Scarborough, England.

Petroleum Products.—America holds the secretariat for ISO/TC 28 on Petroleum Products, the work of the secretariat being handled by Sectional Committee Z11, of which ASTM is sponsor.

A meeting of ISO/TC 28 was held in New York City in June, 1952, and the committee adopted as its scope of work "methods of sampling, methods of test, nomenclature, terminology, and specifications for petroleum and petroleum products."

Rubber.—The secretariat for ISO/TC 45 on Rubber is held by Great Britain. ASTM Committee D-11 is handling the American contacts with this ISO committee. A meeting of ISO/TC 45 is being held in London, England, June

28–30, 1954, at which it is expected America will have several delegates.

Viscosity.—America holds the secretariat for ISO/TC 66 on Viscosity. The subcommittee on Rheological Properties of ASTM Committee E-1 is handling the work of the secretariat.

Plastics.—America holds the secretariat for ISO/TC 61 on Plastics. ASTM Committee D-20 is being looked to to handle the work of the secretariat and has organized for the purpose a special committee consisting of representatives of the various groups interested.

A meeting of ISO/TC 61 is being held in Brighton, England, October 4–8, 1954, at which it is expected America will have a number of delegates.

Shellac.—Subcommittee XIII on Shellac of ASTM Committee D-1 has been set up as the American committee in charge of contacts with ISO/TC 50 on Lac for which India holds the secretariat. America has submitted a number of comments with respect to standards dealing with shellac that are now under consideration.

A meeting of ISO/TC 50 is planned for October, 1954, in London, England.

Solid Mineral Fuels.—ASTM Committee D-5 is handling American contacts with ISO/TC 27 on Solid Mineral Fuels. A meeting of this ISO committee was held in London, England, on November 2–10, 1953, at which America was represented by W. A. Selvig (leader), U. S. Bureau of Mines; O. W. Rees, Illinois State Geological Survey; and W. M. Bertholf, Colorado Fuel and Iron Corp. Consideration was given at the meeting to tests for moisture, gross calorific value, carbon and hydrogen, total sulfur, nitrogen, swelling and caking, phosphorus, chlorine, arsenic, forms of sulfur, mineral matter, ash, volatile matter, and sampling.

Iron and Steel.—A meeting of ISO/TC 17 on Iron and Steel was held in New York City in June, 1952. Consideration was given to draft proposals on Brinell Hardness Test, Rockwell Hardness Test, Vickers Hardness Test, Bend Test, Charpy Impact Test, and Izod Impact Test. Members of ASTM Committee A-1 attended this meeting (as observers) together with members of Committee E-1 subcommittees on Indentation Hardness and Impact Testing.

Chemistry.—Several ASTM committees have indicated an interest in the work of ISO/TC 47 on Chemistry, and draft proposals have been received which have been passed on to the committee.

Laboratory Glassware.—Committee E-1 has indicated that it favors American participation in the work of ISO/TC 48 on the basis of an observer.

Statistical Treatment of Series of Observations.—ASTM Committee E-11 favors American participation in the work of ISO/TC 69. This recommendation is concurred in by the American Society for Quality Control, American Statistical Assn., and Institute of Mathematical Statistics.

Mica.—Subcommittee IX on Mica of ASTM Committee D-9 has been set up to handle the American contacts with ISO/TC 56 for which India holds the secretariat. The subcommittee has submitted comments with respect to standards dealing with mica that are now under consideration.

Copper and Copper Alloys.—The Advisory Committee of ASTM Committee B-5 is being set up to handle the work of the secretariat for ISO/TC 26 on Copper and Copper Alloys.

Paper.—On the recommendation of ASTM Committee D-6 on Paper and Paper Products, America participates in the work of ISO/TC 6 on the basis of an observer. Copies of all proposals are received and referred to Committee D-6 for its information.

Timber.—ASTM Committee D-7 on Wood has indicated that it favors American participation in the work of ISO/TC 55 on Timber.

Raw Materials for Paints, Varnishes, and Similar Products.—ASTM Committee D-1 on Paint, Varnish, Lacquer, and Related Products has indicated that it favors American participation in the work of ISO/TC 35.

Asbestos-Cement Products.—ASTM Committee C-17 on Asbestos-Cement Products has indicated that it favors American participation in the work of ISO/TC 77 on the basis of an observer.

The Administrative Committee on Standards was saddened by the sudden death just prior to the 1953 Annual Meeting of Mr. Lloyd B. Jones who had served as its chairman for three years. Mr. Jones contributed much to the work of the committee. He brought to it a wealth of experience in view of his many years of service with the Pennsylvania Railroad Co. as Assistant Engineer of Motive Power, Master Mechanic, and subsequently Engineer of Tests, and he had participated actively for many years in the work of various ASTM committees. The committee voted a commemorative resolution in his honor at its September, 1953, meeting. Mr. J. H. Foote was elected chairman as Mr. Jones' successor.

Respectfully submitted on behalf of the committee,

J. H. FOOTE,
Chairman.

R. E. HESS,
Secretary.

APPENDIX III

REPORT OF ADMINISTRATIVE COMMITTEE ON RESEARCH

The Administrative Committee on Research held one meeting during the year, at Society Headquarters on November 24, 1953.

At the November meeting, Bruce W. Gonser of Battelle Memorial Inst. was nominated for the office of chairman for the three-year term expiring in June, 1957. This nomination was confirmed by letter ballot of the committee. The terms of W. C. Voss and T. A. Boyd as members of the committee expire this June. Appointment of two new members will be made by the Board of Directors.

The Research Fund has been augmented by a portion of the 1953 membership fees of the Society, amounting to some $3500. This allocation of membership fees to the Research Fund was a regular practice some years ago but was deferred in 1947, 1948, 1949, 1951, and 1952. The present amount in the Principal Account as of March 31, 1954, was $57,718. The Income Account (as of the same date) which is used for assisting the technical committees upon request was $6464.

In addition to the $3000 from the entrance fees and a $187.74 dividend, the Principal Account was augmented during the past year by $500 bequeathed by the late Executive Secretary, C. L. Warwick.

Recognizing how closely allied are the interests of ASTM and those of the National Research Council of the National Academy of Sciences, an article outlining the activities of the National Research Council was published in the February, 1954, issue of the ASTM BULLETIN. The Society is particularly close to the work of the Division of Engineering and Industrial Research of the Research Council and is represented in this Division by Bruce W. Gonser. It is also represented on the National Research Council Advisory Committee on Highway Research by K. B. Woods with W. S. Housel, alternate. An informal liaison is maintained with the NRC Building Research Advisory Board. The Society is also interested in the NRC Committee on Spectral Absorption Data.

The ACR is always gratified to know that progress is being made on various research projects with which it has been concerned, either through advice to the committee or, in some cases, by contributions of funds for the initiation of projects.

The ASTM-ASME Joint Committee on Effect of Temperature on the Properties of Metals has solicited some $80,000 to be used for research in this field. As a result of this work three valuable publications already have resulted, including one on the elevated temperature properties of stainless steels and another on the elevated temperature properties of chromium-molybdenum steels.

Work has been started at Pennsylvania State University (formerly Pennsylvania State College) by Committee C-16 on

Thermal Insulating Materials for research on the effect of moisture on thermal conductivity.

Committee D-7 on Wood has initiated work on the Wood Pole Research Program at the U. S. Forest Products Laboratories. Concerning the financial status to date in round numbers, $68,000 has been actually received, most of which is on a one-year basis with commitments of repeat contributions made. The total estimated amount needed is $160,000.

Committee B-4 on Electrical Heating, Resistance, and Related Alloys, in cooperation with Committee E-3 on Chemical Analysis of Metals, has developed methods for the analysis of six elements in cathode nickel. These methods will be submitted to the Society for approval this June. The analysis of nickel cathodes, a particularly difficult problem, was discussed before the Research Committee, and the present results stem partly from those early discussions.

The Advisory Committee on Corrosion is continuing its work of establishing and maintaining jurisdiction of the ASTM test sites and has indicated that its expenditures have been considerably less than originally estimated.

The "Review of ASTM Research," which has been publicized by a number of journals, has been received with a great amount of interest as evidenced by the more than 1200 individual requests for copies which have been received. These requests represent 42 countries.

"Some Unsolved Problems," which was distributed to about 3000 colleges and industrial and research laboratories, resulted in several hundred letters in response. Many of these suggested new fields of work or contained constructive comments bearing on the problems listed in the pamphlet. Many of the comments received were of sufficient interest to the ASTM membership as a whole that the ACR decided at its last meeting to publish a column in the ASTM BULLETIN under the title "ACR Notes." The first of these columns appeared in the April, 1954, BULLETIN.

Respectfully submitted on behalf of the committee,

W. C. VOSS,
Chairman.

J. S. PETTIBONE,
Secretary.

APPENDIX IV

REPORT OF ADMINISTRATIVE COMMITTEE ON PAPERS AND PUBLICATIONS

In the report of the Administrative Committee on Papers and Publications a year ago, mention was made of the backlog of material awaiting publication that had resulted from the extensive program that marked the Fiftieth Anniversary Meeting of the Society. The past year has been devoted largely to the completion of the many special publications pending as well as taking care of a more than average amount of technical papers. Only two symposiums of the 1953 Annual Meeting are still pending, namely, the Symposium on Dynamic Testing of Soils (STP 156), which is virtually completed, and the very extensive Symposium on Effect of Temperature on the Brittle Behavior of Metals with Particular Reference to Low Temperatures (STP 158). The latter publication will be some 450 pages in size, the material for which has only recently been released by the committee in charge. All of the publications issued in the past year are listed below.

It will be noted that a very considerable number of the papers presented both at the Fiftieth Anniversary Meeting and at the 1953 Annual Meeting have been published as special technical publications. The technical paper portion of the *Proceedings* continues at a reasonably constant level, but the amount of technical material appearing in special technical publications increases. The decision to issue material in special technical publication form is based upon several considerations. The symposiums by and large lend themselves admirably to this form of publication. One of the criteria is that papers on a given subject should be definitely interrelated so that they will form a consistent unit when issued as an STP. One further consideration is that the papers usually deal with a special subject rather than one of general interest. The fact that they are issued as special publications makes it possible for the Society to publish more material of this nature than would otherwise be the case if all technical papers, for example, were to appear in the *Proceedings* or in the ASTM BULLETIN.

There have been several publication ventures during the past year that are of a very special nature. One of these is the issuance of sets of IBM cards which index the available infrared data on a large number of materials. It is expected that this will be extended during the current year to include IBM index cards of ultraviolet data. The Society has published for a number of years for the Joint Committee on Chemical Analysis by Powder Diffraction Methods not only the data cards but an IBM index as well, and the new indices are quite similar in nature. Another project has been the publication of Reference Radiographs for Inspection of Aluminum and Magnesium Castings in the form of comparison films covering aluminum and magnesium castings; this is a companion to the radiographic standards covering steel castings. Work is now under way on an 850-page compilation of viscosity index tables.

Special Committee on Format:

Mention was made a years ago of the formation of a special committee to review the format and make-up of the Society's publications. This committee under the chairmanship of L. S. Reid submitted recommendations, first, with respect to certain changes in the BULLETIN which have for the most part been put into effect. Perhaps of special note is the inclusion of biographies and photographs of authors of BULLETIN papers. Also recommended is the more complete standardization of covers of ASTM publications so that they will immediately be identified as such. It is proposed, for example, to standardize on blue cover stock for all Supplements to the Book of Standards and all compilations of standards. The special technical publications would all be issued in the sepia cover.

A change has been made in the typography of the technical publications in that it is proposed to use a somewhat larger size of type than that heretofore employed for the smaller type size (footnotes and tables).

Change in Size of Publications:

The Administrative Committee is now giving consideration to a proposal that the size of publications be changed from the 6 by 9-in. size to the 8½ by 11-in. size. This had been proposed having primarily reprints of standards in mind, but the proposal carried with it a change in size for all publications. The views of the technical committees were solicited, and many of these committees have already commented. On the basis of the canvass and study that has been made, the Papers' Committee is convinced that no change should be made in the size of the Society's publications in general, but it believes that there may be merit in the proposal to issue separate standards in the 8½ by 11-in. size and this proposal is receiving further study.

Presentation of Papers:

Reference was made a year ago to a proposal to recognize good presentation of papers in order to encourage better presentations on the part of authors and thereby improve the character and interest in technical sessions. The plan, drawn up by a special committee under the chairmanship of R. C. Adams, provides for reporters at each of the sessions, by means of check marks and one word replies, to complete a comprehensive statement on items usually concerned with effective presentation. While this was instituted purely on a trial basis a year ago without foreknowledge on the part of authors, the plan evoked considerable interest and proved to be quite practical. It will be given a more extensive trial at the approaching Annual Meeting. Announcements concerning it have appeared in the ASTM BULLETIN, and each author will be advised in advance that presentations are being evaluated.

Meetings:

Two meetings of the Administrative Committee on Papers and Publications have been held during the year, one on November 18, 1953, and the other on February 11, 1954. In all the Papers Committee reviewed and accepted for publication 180 technical papers.

RECORD OF PUBLICATIONS ISSUED THIS YEAR

Regular Publications:

1953 Proceedings, 1209 pp., 8000 copies.
1953 Supplements to Book of Standards:
  Part 1, 379 pp., 13,500 copies.
  Part 2, 288 pp., 11,000 copies.
  Part 3, 399 pp., 9400 copies.
  Part 4, 174 pp., 8400 copies.
  Part 5, 347 pp., 8400 copies.
  Part 6, 205 pp., 8200 copies.
  Part 7, 307 pp., 8500 copies.
1953 Year Book, 644 pp., 7400 copies.
1953 Index to ASTM Standards, 300 pp., 23,000 copies.
ASTM BULLETIN, 8 issues (May, 1953, to April, 1954), total number of pages 724, average number of copies 11,212 (254 pages of technical papers).

A statement of the volume of the principal publications for the past four years is given below:

Publications	1950–1951 Pages	1951–1952 Pages	1952–1953 Pages	1953–1954 Pages
Proceedings	1480	1332	1335	1209
Book of ASTM Standards	....	....	9976	....
Supplements to Book of ASTM Standards	2179	1916	....	2099
ASTM Methods of Chemical Analysis of Metals	486	....	....	....
Index to ASTM Standards	274	282	300	300
Year Book	588	608	632	644
Special Technical Publications	2796	1221	1606	2604
Other Special Publications	886	16	1182	938
ASTM BULLETIN	772	716	716	724
Totals	9461	6091	15 747	8518

Special Compilations of Standards Published from April 15, 1953, to April 15, 1954:

ASTM Standards on Electrical Heating, Resistance, and Related Alloys (B-4), 244 pp., 1000 copies.
ASTM Standards on Electrodeposited Metallic Coatings (B-8), 95 pp., 2000 copies, plus 3000 copies for International Nickel Co.
ASTM Standards on Petroleum Products and Lubricants (D-2), 916 pp., 6500 copies.
ASTM Standards on Gaseous Fuels (D-3), 184 pp., 1200 copies.
ASTM Standards on Bituminous Constructional Materials (D-4, D-8), 434 pp., 1000 copies—published July, 1953; Supplement published March, 1954, consisting of 13 pp., 750 copies.
ASTM Standards on Paper and Paper Products and Shipping Containers (D-6, D-10), 395 pp., 1200 copies.
ASTM Standards on Wood (D-7), 366 pp., 1500 copies.
ASTM Standards on Textile Materials (D-13), 696 pp., 2000 copies.
ASTM Standards on Engine Antifreezes (D-15), 48 pp., 1200 copies.

Special Compilations in Prospect:

ASTM Specifications for Steel Piping Materials (A-1), 370 pp., 300 copies.
ASTM Standards on Cement (C-1), 266 pp., 2250 copies.
ASTM Standards on Paint, Varnish, Lacquer, and Related Products (D-1), Supplement, 80 pp., 2000 copies.
ASTM Standards on Plastics (D-20), 700 pp., 2000 copies.

Special Publications Issued:

Summary of Proceedings of the Fifty-sixth Annual Meeting, 30 pp., 7600 copies.
1953 Marburg Lecture, "An Excursion in Petroleum Chemistry," by F. D. Rossini, 35 pp., 3000 copies.
1953 Gillett Lecture, "Micrometallurgy—The Metallurgy of Minute Additions," by Jerome Strauss, 23 pp., 4000 copies.
Symposium on Strength and Ductility of Metals at Elevated Temperatures (STP 128), 254 pp., 3000 copies.
Symposium on Continuous Analysis of Industrial Water and Industrial Waste Water (STP 130), 60 pp., 2000 copies.
Symposium on Plastics Testing—Present and Future (STP 132), 75 pp., 2000 copies.
Symposium on Conditioning and Weathering (STP 133), 104 pp., 2500 copies.
Symposium on Tin (STP 141), 115 pp., 2000 copies.
Symposium on Exchange Phenomena in Soils (STP 142), 80 pp., 2000 copies.
Symposium on Light Microscopy (STP 143), 132 pp., 2500 copies.
Symposium on Fretting Corrosion (STP 144), 88 pp., 2500 copies.
Symposium on Interpretation of Non-Destructive Tests (STP 145), 104 pp., 2500 copies.
Fifty Years of Paint Testing (STP 147), 51 pp., 2500 copies.
Symposium on Chemical Analysis of Inorganic Solids by Means of the Mass Spectrometer (STP 149), 39 pp., 2000 copies.
Bibliographical Abstracts of Methods for Analysis of Synthetic Detergents (STP 150), 19 pp., 2000 copies.

Report on the Elevated Temperature Properties of Chromium-Molybdenum Steels (STP 151), 212 pp., 2500 copies.
Symposium on Insulating Oils (Fifth Series) (STP 152), 51 pp., 2000 copies.
Symposium on Porcelain Enamels and Ceramic Coatings as Engineering Materials (STP 153), 128 pp., 2000 copies.
Symposium on Lateral Load Tests on Piles (STP 154), 107 pp., 2000 copies.
Symposium on Techniques for Electron Metallography (STP 155), 150 pp., 2000 copies.
Symposium on Fluorescent X-ray Spectrographic Analysis (STP 157), 74 pp., 2000 copies.
Bibliography of Fatigue References (STP 9-C), 48 pp., 250 mimeographed copies.
Bibliography on Speed of Testing, 20 pp., 500 mimeographed copies.
Cumulative Alphabetical and Grouped Numerical Index of X-ray Diffraction Data (STP 48-D), 651 pp., 1000 copies.
Fifth Set of X-ray Diffraction Cards (STP 48-D), 800 cards, 900 sets.
Manual on Measurement and Sampling of Petroleum and Petroleum Products, 147 pp., 5000 copies.
Proposed Procedures for Emission Spectrochemical Analysis, 317 pp., 2500 copies.
Index to the Literature on Spectrochemical Analysis, Part III, 230 pp., 2500 copies.
ASTM Viscosity Tables for Kinematic Viscosity Conversions and Viscosity Index Calculations (STP 43-A), 62 pp., 5500 copies.
ASTM-Wyandotte Infrared Index Cards, 7705 cards.
Numerical Index of Abstracted Infrared Spectra Indexed on Wyandotte ASTM Punched Cards, 32 pp., 500 copies.
Codes and Instructions for Wyandotte-ASTM Punched Cards, 28 pp., 1000 copies.
Reference Radiographs for Inspection of Aluminum and Magnesium Castings, 62 pp. plus 107 negatives, 25 copies.
ASTM Manual on Calibrating Liquid Containers—Upright Tanks, 102 pp., 2000 copies.

Special Publications in Prospect:

Symposium on Dynamic Testing of Soils (STP 156), 253 pp., 2000 copies.
Symposium on Effect of Temperature on the Brittle Behavior of Metals with Particular Reference to Low Temperatures (STP 158), 450 pp., 2000 copies.
Symposium on Radioactivity—Isotopes and Tracer Techniques (STP 159), 72 pp., 2000 copies.
Report on Elevated Temperature Properties on Selected Super-Strength Alloys (STP 160), 2500 copies (size not yet determined).
Bibliography on Electrical Contacts (STP 56-G), 79 pp., 1200 copies.
Appendix to ASTM Manual of Engine Test Methods for Rating Fuels, 44 pp., 3000 copies.
Viscosity Index (STP 42-A), 850 pp., 5000 copies.
Symposium on Diesel Fuels (STP 161), 52 pp., 2000 copies.
Symposium on Color of Transparent, Translucent Products (STP 162), 55 pp., 2000 copies.

Reprints:

Cotton Yarn Appearance Standards, Series 1—50; 2—90; 3—90; 4—90; 5—60.
Radiography of Steel Castings, 50 sets each of X-ray and Gamma ray, 32 negatives in each.

CURRENT ACTIVITIES

The program in prospect for the 1954 Annual Meeting, with a number of symposiums scheduled as listed below, is again well rounded.

Symposium on Coal Sampling.
Symposium on Temperature Stability of Electrical Insulating Materials.
Symposium on Odor.
Symposium on Permeability of Soils.
Symposium on Effect of Cyclic Heating and Stressing of Metals at Elevated Temperatures.
Symposium on Methods of Testing Constructions.
Significance of Tests of Concrete.

Respectfully submitted on behalf of the committee,

R. E. HESS,
Chairman.

APPENDIX V

REPORT OF ADMINISTRATIVE COMMITTEE ON DISTRICT ACTIVITIES

Twenty-five ASTM District Meetings were held during the June, 1953, to June, 1954 year, sponsored by the 14 districts; this includes the Washington, D. C., meeting held in conjunction with the ASTM Spring Meeting. Guest speaker at this meeting was Mr. Charles S. Thomas, then Assistant Secretary of Defense, Logistics and Supply, who addressed more than 275 ASTM members and guests and their wives on "Standardization in the Department of Defense." The only districts that did not hold meetings during the year were Chicago and Cleveland.

The Philadelphia District Council, in addition to sponsoring three District Meetings, acted as host for the Fifty-sixth Annual Meeting held in Atlantic City. The council planned the ladies' entertainment and handled details of the annual dinner, underwriting and sponsoring the entertainment program.

Other examples of how the districts and their councils aid in national meetings should be noted. The Chicago District Council provided the nucleus for the expanded Committee on Arrangements for the 1954 Annual Meeting and Exhibit. And for the 1956 Second Pacific Area National Meeting being held in Los Angeles, September 16–22, 1956, both the Southern and the Northern California District Council memberships were the basis on which the general committee has been set up.

President L. C. Beard, Jr., made an extended series of addresses on behalf of the Society, speaking at 14 locations throughout the country. Several of his engagements were in areas which heretofore have not been privileged to hear an ASTM president. These included Dallas, Tex. (Southwest), the Tacoma-Seattle, Wash., area, Indianapolis, Ind. (Ohio Valley), and Storrs, Conn. (New England). A joint meeting was held in Richland, Wash., with the American Society of Mechanical Engineers, American Institute of Chemical Engineers, American Society for Metals, and the American Chemical Society. The stopover in Richland was highly successful and was the third time in as many years that an ASTM president has spoken in that area. President Beard's other engagements included the New York, Pittsburgh, Western New York-Ontario (Buffalo), St. Louis, Southwest (Houston), Southern California (Alhambra), Northern California (Berkeley), Philadelphia (Wilmington, Del.), and Detroit Districts. His talk, "Something Has Been Added," was directed to the average technical man rather than to those most familiar with the petroleum and petrochemical fields. His presentation was essentially the same at all locations except Storrs, where he gave a shorter address on "Some Highlights of Petroleum Technology."

Many of the more successful district

meetings have been held in conjunction with local chapters of other societies such as the National Association of Corrosion Engineers, American Society for Metals, Engineers Club of St. Louis, Society of Automotive Engineers, American Society of Lubrication Engineers, American Chemical Society, American Society of Chemical Engineers, American Society for Quality Control, and Technical Association of the Pulp and Paper Industry. The details of the district meetings are listed in the table of meetings included in the body of the Board of Directors' report.

The Administrative Committee on District Activities sponsored, as it has for the past several years, a meeting during the Annual Meeting attended by the officers of the various ASTM districts of the Society. A meeting of the ACDA was also held during the Annual Meeting and a number of suggestions resulted, aimed towards facilitating the work of the various districts. Beginning with the 1954 elections of district councilors, those nominees who have had previous service on the council will be so indicated on the ballot. The ACDA accepted the offer of the Administrative Committee on Research to prepare a list of potential speakers for distribution to various districts. This should be helpful to the program chairmen in selecting a suitable program.

For each district meeting, printed notices were prepared and distributed. Even though many of those receiving the notices may not have been able to attend the meeting, they were apprised of the speaker and the subject and, through the listing of the councilors of the ASTM district, each would have information on those who are responsible for directing the district work in that locale.

Respectfully submitted on behalf of the committee,

C. M. GAMBRILL,
Chairman.

REPORT OF COMMITTEE A-1

ON

STEEL*

Since the July 3, 1953, meeting of Committee A-1 on Steel, many important items on standardization of steel products have been approved by the Administrative Committee on Standards. These are outlined in another section of the report. Suffice it to say that 45 separate actions by the Administrative Committee were involved. In the 1952 Report of Committee A-1 to the Society 31 actions were requested. This trend of submitting more actions to the Administrative Committee on Standards than to the Society at the Annual Meeting has continued for about three years in Committee A-1.

One of the important series of actions taken was the withdrawal of Emergency Alternate Provisions covering alternate compositions for alloy steel bars and Emergency Alternate Provisions permitting a decrease in the molybdenum content of some of the alloy steel piping materials for high-temperature service. These withdrawals came as a result of the lifting of government restrictions on nickel and molybdenum.

Other withdrawals included the Tentative Methods and Definitions for Mechanical Testing of Steel Bars (A 330 - 51 T)[1] and the Tentative Methods and Definitions for Mechanical Testing of Structural Steel (A 359 - 52 T).[1] The provisions in these documents have been incorporated in the Tentative Methods and Definitions for the Mechanical Testing of Structural Steel (A 370 - 53 T).[2] Appended to this report is a proposed Supplement III to Methods A 370 covering testing methods and definitions peculiar to steel fasteners.[3]

Three new specifications, all of particular significance, have been approved for publication, including the Tentative Specifications for Ferritic Alloy Steel Forged and Bored Pipe for High-Temperature Service (A 369 - 53 T),[2] Tentative Specifications for Carbon and Alloy Steel Forgings for Pressure Vessel Shells (A 372 - 53 T),[2] and the Tentative Specification for Structural Steel for Welding (A 373 - 54 T).[4]

The mid-winter meeting of Committee A-1 was held in Pittsburgh on January 27, 1954. Fifteen subcommittees and sections met on January 25 and 26. The attendance was excellent, and the many actions taken are covered in the Appendix to this report.[5]

Personnel.—As a result of personnel changes during the past year, the committee consists of 295 voting members, including 133 producers, 119 consumers, and 43 general interest members.

At the July 3, 1953, meeting N. L. Mochel resigned as chairman of Committee A-1 after 15 years continuous service in that capacity. Also, because of retirement, T. G. Stitt resigned his two positions as Vice-Chairman of Committee A-1 and Chairman of Subcommittee IX on Steel Tubing and Pipe. The officers elected to fill the vacancies in the terms of Committee A-1 officers until 1954 were H. B. Oatley, Great Neck, L. I., N. Y., as chairman; and W. F. Collins of the New York Central System, and C. E. Loos of the United States Steel Corp., as vice-chairmen.

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13–18, 1954.

[1] 1952 Book of ASTM Standards, Part 1.

[2] 1953 Supplement to Book of ASTM Standards, Part 1.

[3] The proposed revision was accepted by the Society and appears in the 1954 Supplement to Book of ASTM Standards, Part 1.

[4] Available as a separate reprint.

[5] See p. 97.

In deference to his 15 years of outstanding service, Mr. Mochel was presented at the Pittsburgh meetings of Committee A-1 with an engraved silver platter and an engrossed scroll signed by many of the Committee A-1 members.

Subcommittee IV on Spring Steel and Steel Springs lost a very able leader when C. T. Edgerton resigned as chairman after 15 continuous years in that capacity. T. R. Weber of the Railway Spring Division, American Locomotive Co., has accepted appointment as the new chairman.

In Subcommittee IX, because of the retirement of T. G. Stitt, C. L. Clark of the Timken Roller Bearing Co. was appointed as the new chairman. Mr. Stitt had served 19 continuous years as chairman of Subcommittee IX. H. R. Redington, National Tube Co., was appointed vice-chairman and secretary, and R. K. Akin, Combustion Engineering, Inc., was appointed consumer vice-chairman.

J. R. LeCron, Bethlehem Steel Co., is the new vice-chairman of Subcommittee XI on Steel for Boilers and Pressure Vessels.

In view of his appointment as the new chairman of Subcommittee IX, C. L. Clark relinquished his office as secretary of Subcommittee XXII on Valves, Fittings, Piping, and Flanges for High Temperature and Subatmospheric Temperatures, and C. J. Boyle of the General Electric Co. was appointed in his place.

In recognition of their long and efficient service to Committee A-1, T. G. Stitt, C. T. Edgerton, and A. E. White have been elected as honorary members of the committee.

During the year M. B. Higgins of the Texas Co. (now retired), W. S. Scott of the Republic Steel Corp., and G. A. Remley of Westinghouse Electric Corp. were elected to special two-year terms on the Advisory Committee.

Other special appointments during the year included J. J. Kanter to represent Committee A-1 on Committee E-8 on Nomenclature and Definitions, W. H. Mayo to represent Committee A-1 on Committee E-11 on Quality Control of Materials, and H. L. Fry to represent Committee A-1 on Subcommittee I on Calibration of Mechanical Testing Machines and Apparatus of Committee E-1.

With great regret the committee records the death during the past year of several present and former well-known members, including Werner Finster, John Howe Hall, Lloyd B. Jones, Raymond D. Lepley, Thomas D. Sedwick, Robert W. Steigerwalt, and Horace G. Swan. Both Mr. Jones and Mr. Steigerwalt were honorary members of the committee.

Before his retirement in 1948, Mr. Jones was Engineer of Tests for the Pennsylvania Railroad and gave unstintingly the benefit of his knowledge and sound judgment in the operation of Committee A-1.

Mr. Steigerwalt, before his retirement in 1952, was metallurgical engineer in charge of railroad materials and commercial forgings for the United States Steel Corp. He served as chairman of Subcommittee VII on Rolled Steel Wheels and Steel Tires for 24 consecutive years, from 1928 to 1952.

John Howe Hall was a pioneer in the heat treatment of steel and contributed in many ways to the development of the steel founder's art. Since 1945 he had been engaged in consulting practice.

Werner Finster was Chief Metallurgist,

Textile Machine Works, Foundry Division, but during his activity in Committee A-1 several years ago, he represented the American Chain and Cable Co. Mr. Swan was Engineer of Tests, Gould Coupler Works, The Symington-Gould Corp., and had represented his company on the committee since 1947.

Mr. Lepley, Construction Engineer, Atlantic Refining Co., was extremely active in subcommittee work on tubular products and piping materials. He had been a member of the committee for 15 years, since 1938. Before retirement, Mr. Sedwick had been Engineer of Tests, Chicago, Rock Island, and Pacific Railway Co. He had been a member of the Society since 1916 and for a great number of those years active in Committee A-1.

RECOMMENDATIONS ACCEPTED BY THE ADMINISTRATIVE COMMITTEE ON STANDARDS

On September 9, 1953, the Administrative Committee on Standards accepted the recommendation of Committee A-1 that the Emergency Alternate Provisions relating to molybdenum content in the following specifications be withdrawn:

Specifications for:

Forged or Rolled Alloy-Steel Pipe Flanges, Forged Fittings, and Valves and Parts for High-Temperature Service (A 182 – 53 T),
Alloy-Steel Castings for Pressure Containing Parts Suitable for High-Temperature Service (A 217 – 53 T),
Seamless Ferritic Alloy Steel Pipe for High-Temperature Service (A 335 – 52a T),
Ferritic Steel Castings for Pressure Containing Parts Suitable for Low-Temperature Service (A 352 – 52 T),
Seamless Low-Carbon and Carbon-Molybdenum Steel Still Tubes for Refinery Service (A 161 – 53 T),
Seamless Cold-Drawn Intermediate Alloy-Steel Heat-Exchanger and Condenser Tubes (A 199 – 52 T),
Seamless Intermediate Alloy-Steel Still Tubes for Refinery Service (A 200 – 53 T),
Seamless Carbon-Molybdenum Alloy-Steel Boiler and Superheater Tubes (A 209 – 51 T),
Seamless Alloy Steel Boiler, Superheater, and Heat Exchanger Tubes (A 213 – 52 T), and
Electric-Resistance-Welded Carbon-Molybdenum Alloy-Steel Boiler and Superheater Tubes (A 250 – 53 T).

The following recommendations submitted by Committee A-1 were accepted by the Administrative Committee on Standards on December 16, 1953:

Tentative Specifications for:

Ferritic Alloy-Steel Forged and Bored Pipe for High-Temperature Service (A 369 – 53 T), and
Carbon and Alloy-Steel Forgings for Pressure Vessel Shells (A 372 – 53 T).

Revision of Tentative Specifications for:

General Requirements for Structural Steel (A 6 – 53 T),
Seamless Cold-Drawn Low-Carbon Steel Heat-Exchanger and Condenser Tubes (A 179 – 53 T),
Alloy-Steel Bolting Materials for High-Temperature Service (A 193 – 53a T),
Seamless Cold-Drawn Intermediate Alloy-Steel Heat-Exchanger and Condenser Tubes (A 199 – 53 T),
Seamless Intermediate Alloy-Steel Still Tubes for Refinery Service (A 200 – 53a T),
Seamless Alloy-Steel Boiler, Superheater, and Heat-Exchanger Tubes (A 213 – 53 T),
Electric-Resistance-Welded Steel Heat-Exchanger and Condenser Tubes (A 214 – 53 T),
Carbon Steel Forgings for Locomotives and Cars (A 236 – 53 T),
Low-Alloy Structural Steel (A 242 – 53 T),
Welded Austenitic Stainless Steel Boiler, Superheater, Heat Exchanger and Condenser Tubes (A 249 – 53a T),
Quenched and Tempered Steel Bolts and Studs with Suitable Nuts and Plain Washers (A 325 – 53 T),
Seamless Ferritic Alloy-Steel Pipe for High-Temperature Service (A 335 – 53 T),
Low-Carbon High-Nickel Steel Plate for Pressure Vessels (A 353 – 53 T), and
Quenched and Tempered Alloy-Steel Bolts and Studs with Suitable Nuts (A 354 – 53a T).

Withdrawal of Tentative:

Methods for Mechanical Testing of Structural Steel (A 359 – 52 T), and
Methods and Definitions for Mechanical Testing of Steel Bars (A 330 – 51 T).

Withdrawal of Emergency Alternate Provisions in Specifications for:

Heat-Treated Alloy-Steel Bars (EA-A 286),
Alloy-Steel Bars to End-Quench Hardenability Requirements (EA-A 304),
Hot-Rolled Alloy-Steel Bars (EA-A 322), and
Cold-Finished Alloy-Steel Bars (EA-A 331).

The new and revised specifications appear in the 1953 Supplement to Book of ASTM Standards, Part 1, bearing the designations indicated above.

On January 13, 1954, the Administrative Committee on Standards accepted the following recommendations of Committee A-1:

Revision of Tentative Specifications for:

Open-Hearth Iron Plates of Flange Quality (A 129 - 53 T),
Carbon-Silicon Steel Plates of Intermediate Tensile Ranges for Fusion-Welded Boilers and Other Pressure Vessels (A 201 - 53 T),
Chromium-Manganese-Silicon (CMS) Alloy-Steel Plates for Boilers and Other Pressure Vessels (A 202 - 53 T),
Nickel-Steel Plates for Boilers and Other Pressure Vessels (A 203 - 53 T),
Molybdenum-Steel Plates for Boilers and Other Pressure Vessels (A 204 - 53 T),
High Tensile Strength Carbon-Silicon Steel Plates for Boilers and Other Pressure Vessels (A 212 - 53 T),
Manganese-Vanadium Steel Plates for Boilers and Other Pressure Vessels (A 225 - 53 T),
Low and Intermediate Tensile Strength Carbon-Steel Plates of Flange and Firebox Qualities (Plates 2 in. and Under in Thickness) (A 285 - 53 T),
High Tensile Strength Carbon-Manganese-Silicon Steel Plates for Boilers and Other Pressure Vessels (A 299 - 53 T),
Chromium-Molybdenum Steel Plates for Boilers and Other Pressure Vessels (A 301 - 53 T),
Manganese-Molybdenum Steel Plates for Boilers and Other Pressure Vessels (A 302 - 53 T), and
Low-Carbon High-Nickel Steel Plate for Pressure Vessels (A 353 - 53 T).

The revised specifications appear in the 1953 Supplement to Book of ASTM Standards, Part 1, bearing the designations indicated above.

On March 31, 1954, the Administrative Committee on Standards accepted the Tentative Specification for Structural Steel for Welding (A 373 - 54 T). The new specification is available as a separate reprint.

RECOMMENDATIONS AFFECTING STANDARDS

Committee A-1 is presenting for publication 3 new tentatives and is recommending the revision of 30 tentatives and 11 standards, and the adoption as standard of 26 tentatives and 1 tentative revision of a standard. In addition one standard is recommended to be reverted to tentative with revision and one tentative to be withdrawn.

The standards and tentatives affected, together with the revisions recommended, are given in detail in the Appendix.[5]

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[6]

ACTIVITIES OF SUBCOMMITTEES

The over-all activity of the committee is too broad to be covered in detail, but several of the more important functions are discussed below:

Subcommittee IV on Spring Steel and Steel Springs continues to study two new specifications for chromium-silicon steel wire, one for valve spring quality and the other for commercial quality. These will probably be ready for publication late in 1954 or early in 1955.

New bend test requirements for deformed bars covered by Tentative Specifications A 15 for Billet Steel Concrete Reinforcement have been under discussion in Subcommittee V on Steel Reinforcement Bars for several years. It is expected that this proposed action will be consummated very shortly.

Subcommittee VI on Steel Forgings

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[6] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

and Billets is emerging from a difficult situation created by the Tentative Specification A 21 for Carbon-Steel Axles for Cars and Tenders.[1] If the requirements were revised to bring the specification into agreement with the AAR Specification M-101, the producers of axles for general industrial use and export would be unable to use the A 21 specification. It has been decided to bring Specification A 21 into line with AAR requirements and to draft a new specification for carbon steel axles for general industrial use and export. The trade association in the closed die forging industry has been contacted by Subcommittee VI, and has agreed to cooperate in organizing a task group to prepare a general specification for this product.

A new specification for high-strength electric fusion welded pipe for gas transmission line service is being developed in Subcommittee IX on Steel Tubing and Pipe, in answer to a request by the ASA Sectional Committee B 31 on Code for Pressure Piping. Subcommittee XXII on Valves, Fittings, Pipings and Flanges for High Temperatures and Subatmospheric Temperatures is drafting a specification for forged and bored seamless austenitic steel pipe for high-temperature service.

Subcommittee XV on Bar Steels is developing a general requirement specification for bar steels, along the lines of Specification A 6 for Structural Steel[2] and Specification A 20 for Flange and Firebox Quality Plates.[1]

The Alloy Steel Chain Institute is working with the Advisory Group of Committee A-1 in organizing a special subcommittee to prepare specifications for alloy steel chain.

In the field of steel fasteners Subcommittee XXVI on Bolting has been assigned the task of drafting specifications for structural steel rivets in answer to a request from the Industrial Fasteners' Inst. Another new specification underway covers transmission tower bolting.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, H. B. Oatley.
Vice-Chairman, W. F. Collins.
Vice-Chairman, C. E. Loos.
Secretary, H. L. Fry.

This report has been submitted to letter ballot of the committee, which consists of 295 members; 194 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

H. B. OATLEY,
Chairman.

J. S. WORTH,
Secretary.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee A-1 presented to the Society through the Administrative Committee on Standards the following recommendations:

Tentative Specifications for:

Metal-Arc Welded Steel Pipe for High-Pressure Transmission Service (A 381 – 54 T).

Revision of Tentative Specifications for:

Billet-Steel Bars for Concrete Reinforcement (A 15 – 54 T),
General Requirements for Delivery of Rolled Steel Plates of Flange and Firebox Qualities (A 20 – 52 T),
Boiler and Firebox Steel for Locomotives (A 30 – 52a T),

Open-Hearth Iron Plates of Flange Quality (A 129 – 53 T),
Carbon-Silicon Steel Plates of Intermediate Tensile Ranges for Fusion-Welded Boilers and Other Pressure Vessels (A 201 – 53 T),
Chromium-Manganese-Silicon (CMS) Alloy-Steel Plates for Boilers and Other Pressure Vessels (A 202 – 53 T),
Nickel-Steel Plates for Boilers and Other Pressure Vessels (A 203 – 53 T),
Molybdenum-Steel Plates for Boilers and Other Pressure Vessels (A 204 – 53 T),
High Tensile Strength Carbon-Silicon Steel Plates for Boilers and Other Pressure Vessels (A 212 – 54 T),
Manganese-Vanadium Steel Plates for Boilers and Other Pressure Vessels (A 225 – 53 T),
Low and Intermediate Tensile Strength Carbon-Steel Plates of Flange and Firebox Qualities (Plates 2 in. and Under in Thickness) (A 285 – 53 T),
High Tensile Strength Carbon-Manganese-Silicon Steel Plates for Boilers and Other Pressure Vessels (A 299 – 53 T),
Steel Plates for Pressure Vessels for Service at Low Temperatures (A 300 – 54 T),
Chromium-Molybdenum Steel Plates for Boilers and Other Pressure Vessels (A 301 – 54 T),
Manganese-Molybdenum Steel Plates for Boilers and Other Pressure Vessels (A 302 – 53 T),
Low-Carbon High-Nickel Steel Plate for Pressure Vessels (A 353 – 53 T), and
5 per cent Chromium, 0.5 per cent Molybdenum Steel Plates for Boilers and Other Pressure Vessels (A 357 – 52 T).

Withdrawal of Emergency Alternates (Relating to Phosphorus) in Specifications for:

Seamless Cold-Drawn Intermediate Alloy-Steel Heat-Exchanger and Condenser Tubes (EA – A 199),
Seamless Intermediate Alloy-Steel Still Tubes for Refinery Service (EA – A 200),
Seamless Alloy-Steel Boiler, Superheater, and Heat Exchanger Tubes (EA – A 213),
Welded Austenitic Stainless Steel Boiler, Superheater, Heat Exchanger, and Condenser Tubes (EA – A 249),
Seamless and Welded Ferritic Stainless Steel Tubing for General Service (EA – A 268),
Seamless and Welded Austenitic Stainless Steel Tubing for General Service (EA – A 269),
Seamless and Welded Austenitic Stainless Steel Sanitary Tubing (EA – A 270),
Seamless Austenitic Chromium-Nickel Steel Still Tubes for Refinery Service (EA – A 271), and
Seamless and Welded Austenitic Stainless Steel Pipe (EA – A 312).

Tentative Specifications A 381 – 54 T were accepted by the Standards Committee on September 28, 1954, and the other recommendations were accepted on October 4, 1954; the new and revised specifications appear in the 1954 Supplement to Book of ASTM Standards, Part 1.

APPENDIX

RECOMMENDATIONS AFFECTING STANDARDS ON STEEL

In this Appendix recommendations are given affecting certain specifications, both standard and tentative, covering various steel products. These specifications appear in their present form in either the 1952 Book of ASTM Standards, Part 1, or in the 1953 Supplement, Part 1, as indicated by the footnote reference.

Revisions in Pipe and Tubing Specifications—Reference to Methods A 370—Check and Ladle Analysis.—In the following pipe and tubing specifications add a note to the scope paragraph to read as follows:

> Note.—For testing methods not specifically covered in these specifications, reference can be made to the Tentative Methods and Definitions for the Mechanical Testing of Steel Products (ASTM Designation: A 370)[2] with particular reference to Supplement II on Steel Tubular Products of Methods A 370.

Also in all cases in the listing below where the specification is preceded by an asterisk, change the tables of chemical analysis to eliminate dual tables showing ladle and check analysis and substitute a single table covering the ranges now shown as check analysis, the new table to be titled "Chemical Composition." All references to ladle analysis not in conformance with this change are to be editorially revised.

*A 53 - 52 T[1]
*A 83 - 52 T[1]
A 120 - 47[1]
A 134 - 53[1]
*A 135 - 51 T[1]
*A 139 - 53[1]
*A 161 - 53 T[2]
*A 178 - 53 T[2]
*A 179 - 53 T[2]
*A 192 - 51 T[1]
*A 199 - 53 T[2]
*A 200 - 53 aT[2]
*A 209 - 51 T[1]
*A 210 - 52 T[1]
A 211 - 44[1]
*A 213 - 53 T[2]
*A 214 - 53 T[2]
*A 226 - 53 T[2]
A 249 - 53 aT[2]
*A 250 - 53 T[2]
A 252 - 46[1]
A 253 - 51 T[1]
*A 254 - 51 T[1]
A 268 - 53[2]
A 269 - 52[1]
A 270 - 50[1]
A 271 - 53[2]
A 312 - 51 T[1]
A 333 - 50 T[1]
A 334 - 51 T[1]

New Tentatives

The committee recommends that the following three new tentatives, as appended hereto, be accepted for publication as tentative:

Tentative Specifications for Low Alloy High Tensile Hot-Rolled Sheets and Strip:[3]

Tentative Specifications for Low Alloy High Tensile Cold-Rolled Sheets and Strip:[3]

These specifications cover low-alloy sheets and strip intended for structural and miscellaneous purposes where greater strength is required and atmospheric corrosion resistance equal to or better than plain copper steel is important. They are written to provide a need expressed by the steel industry.

Tentative Specifications for Seamless Austenitic Steel Pipe for High-Temperature Central Station Service:[3]

The power industry has requested that these specifications be written to provide suitable seamless pipe for central station service where higher operating temperatures are required. Four grades of austenitic steel are covered.

Revisions of Tentatives

The committee recommends revisions in the following 18 tentatives:

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[1] 1952 Book of ASTM Standards, Part 1.

[2] 1953 Supplement to Book of ASTM Standards, Part 1.

[3] The new tentatives were accepted by the Society and appear in the 1954 Supplement to Book of ASTM Standards, Part 1.

Tentative Specification for General Requirements for Delivery of Rolled Steel Plates, Shapes, Sheet Piling, and Bars for Structural Use (A 6 – 53 T):[2]

Section 11(b).—Change the words "outside the middle third of the gage length of an 8-in. specimen" to read "outside the middle half of the gage length of an 8-in. specimen."

Tentative Specifications for Billet Steel Bars for Concrete Reinforcement (A 15 – 52 T):[1,1a]

Tentative Specification for Rail Steel Bars for Concrete Reinforcement (A 16 – 52 T):[1]

Table III.—Add the following footnote reference after the title of the table: "On plain bars whose application is in unbent form such as load transfer dowels, the cold bend test shall be waived."

Tentative Specifications for Seamless Steel Boiler Tubes (A 83 – 52 T):[1]

Table III.—Revise footnote *e* to read as follows by the addition of the italicized words: "Permissible variations in length apply to tubes before bending. *These tolerances apply to cut lengths up to and including 24 ft. For lengths over 24 ft an additional over tolerance of $\frac{1}{8}$ in. for each 10 ft or fraction thereof shall be permissible, up to a maximum tolerance of $\frac{1}{2}$ in.*"

Tentative Specifications for Axle-Steel Bars for Concrete Reinforcement (A 160 – 52 T):[1]

Table III.—Revise as indicated above for Table III in Specifications A 15 and A 16.

Tentative Specifications for Seamless Low-Carbon and Carbon-Molybdenum Steel Still Tubes for Refinery Service (A 161 – 53 T):[2]

TABLE I.—PERMISSIBLE VARIATIONS IN DIMENSIONS AND WEIGHT OF STILL TUBES.

Size Outside Diameter, in.	Outside Diameter, in.		Specified Wall Thickness,		Calculated Weight per foot, per cent		Cut Length, in.	
	Over	Under	Over	Under	Over	Under	Over	Under
HOT-ROLLED STILL TUBES								
Over 7½ to 9, incl.	1/64	1/16	28	0	5	5	3/16	0
COLD-DRAWN STILL TUBES								
Over 7½ to 9, incl.	0.015	0.045	22	0	5	5	3/16	0

Table III.—Revise by adding th permissible variations in dimension and weight shown in the accompanying Table I.

Table IV.—Revise by adding the following plug gage formulas for tubes over $7\frac{1}{2}$ to 9 in., incl., in outside diameter:

Hot-Rolled Still Tubes .... $PG = D - \dfrac{2t}{0.875} - 0.115$

Cold-Drawn Still Tubes .... $PG = D - \dfrac{2t}{0.90} - 0.090$

Tentative Specifications for Electric-Resistance-Welded Steel and Open-Hearth Iron Boiler Tubes (A 178 – 53 T):[2]

Table IV.—Revise footnote *d* as indicated above for footnote *e* of Table III in Specifications A 83.

Tentative Specifications for Cold-Drawn Low-Carbon Steel Heat-Exchanger and Condenser Tubes (A 179 – 53 T):[2]

[1a] See Editorial Note, p. 95.

Table I.—In footnote *b* covering length tolerances for lengths over 24 ft, add as a final phrase the words "up to a maximum of ½ in."

Tentative Specifications for Welded Steel Wire Fabric for Concrete Reinforcement (A 185 – 53 T):[2]

Section 11(b).—Revise to read: "Transverse wires shall not project beyond the centerline of each longitudinal edge wire more than a distance of 1 in., unless otherwise specified."

Tentative Specifications for Seamless Cold-Drawn Intermediate Alloy-Steel Heat-Exchanger and Condenser Tubes (A 199 – 53 T):[2]

Table I.—For grade T9 revise the required silicon content range from the present "0.50 to 1.00" to read "0.25 to 1.00" per cent.

Table III.—Revise footnote *b* as indicated above for footnote *b* of Table I in Specifications A 179.

Tentative Specifications for Seamless Intermediate Alloy-Steel Still Tubes for Refinery Service (A 200 – 53aT):[2]

Table III.—Revise by adding the permissible variations in dimensions and weight shown in the accompanying Table I.

Table IV.—Revise as indicated above for Table IV in Specifications A 161.

Tentative Specification for High Tensile Strength Carbon-Silicon Steel Plates for Boilers and Other Pressure Vessels (A 212 – 53 T):[1a,2]

Section 1.—In the second sentence change the maximum thickness of firebox quality plate from "6 in." to read "8 in."

Table I.—In the listings for maximum carbon content change "For plates over 2 to 6 in., incl, in thickness" to read "For plates over 2 to 8 in., incl, in thickness."

Table III.—In the listings of material thickness for bend test requirements change "Over 4½ to 6, incl" to read "Over 4½ to 8, incl."

Tentative Specifications for Seamless Alloy Steel Boiler, Superheater, and Heat Exchanger Tubes (A 213 – 53 T):[2]

Table VI.—Revise footnote *e* as indicated above for footnote *b* of Table I in Specifications A 179.

Tentative Specifications for Electric-Resistance-Welded Steel Heat-Exchanger and Condenser Tubes (A 214 – 53 T):[2]

Table I.—Revise footnote *a* as indicated above for footnote *b* of Table I in Specifications A 179.

Tentative Specifications for Welded Austenitic Stainless Steel Boiler, Superheater, Heat Exchanger and Condenser Tubes (A 249 – 53aT):[2]

Table IV.—Revise footnote *e* as indicated above for footnote *b* of Table I in Specifications A 179.

Tentative Specification for Steel Plates for Pressure Vessels for Service at Low Temperatures (A 300 – 53 T):[1a,2]

Section 3(c).—Revise to read as follows:

> (*c*) If the average value of the three specimens is below 15 ft lb, with not more than one specimen below 10 ft lb, a retest of three additional specimens shall be made, each of which must equal or exceed the specified minimum value of 15 ft lb. If the required values are not obtained upon retest or if the values on the initial test are below the minimum required for retest, the plate may be reheat treated. After reheat treatment, a set of three specimens shall be made, each of which must equal or exceed the specified minimum value of 15 ft lb.

Tentative Specification for Chromium-Molybdenum Steel Plates for Boilers and Other Pressure Vessels (A 301 – 53 T):[1a,2]

Section 4(a).—Revise the first sentence to read as follows by the addition of the italicized word: "All plates shall be treated to produce grain refinement, either by *annealing*, normalizing, or heating uniformly for hot forming."

Table I.—For grade B reduce the permissible maximum carbon content

from the present "0.21" to read "0.17" per cent.

Tentative Methods and Definitions for Mechanical Testing of Steel Products (A 370 – 53 T):[2]

Section 1(c).—In the tabulation of supplements include: "Fasteners (Supplement III) . . . Sections F1 to F6."

New Supplement.—Add a new Supplement III on Fasteners covering Sections F1 to F6 to read as appended to this report.[4]

WITHDRAWAL OF TENTATIVE

Tentative Specifications for Rolled Carbon-Steel Locomotive Frames (A 287 – 46 T):[1]

It is recommended that these specifications be discontinued since the product is no longer in demand and is not being manufactured.

REVISION OF STANDARD AND REVERSION TO TENTATIVE

The committee recommends revisions as outlined in the following standard with reversion to tentative:

Standard Specifications for Open-Hearth Carbon-Steel Rails (A 1 – 53):[2]

Section 11.—Revise Paragraphs (*b*), (*c*) and (*d*) to read as follows:

(*b*) If all of these specimens withstand the above drop test without breaking between the supports all of the rails of the heat will be accepted subject to final inspection for surface, section and finish.

(*c*) If any specimen breaks in a location other than between the supports, the test shall be disregarded and a retest shall be taken from the top of the rail involved.

(*d*) If one of the three specimens fails, subject to the requirements of Paragraph (*c*) all of the "A" rails of the heat shall be rejected. Specimens shall then be cut from the bottom end of the same "A" rails or the top end of the "B" rails of the same ingots and tested subject to Paragraph (*c*). If any of these specimens fail, the "B" rails of the heat shall be rejected. Three additional specimens shall then be taken from the bottom end of the "B" rails or the top end of the "C" rails of the same ingots and tested subject to Paragraph (*c*). If none of these specimens fails, the balance of the heat shall be accepted subject to final inspection for surface, section and finish. If any of these specimens fail, the entire heat shall be rejected.

ADOPTION AS STANDARD OF TENTATIVE REVISION OF STANDARD

Standard Specifications for Heat-Treated Carbon-Steel Bolting Material (A 261 – 47):[1]

The committee recommends that the present tentative revision of Section 12 be adopted as standard and incorporated in these specifications.

ADOPTION OF TENTATIVES AS STANDARDS

The committee recommends that the following 17 specifications and 1 method appearing in the 1952 Book of ASTM Standards, Part 1, be approved for reference to letter ballot of the Society for adoption as standard without revision:

Tentative Specifications for:

Open-Hearth Steel Girder Rails of Plain, Grooved, and Guard Types (A 2 – 49 T),
Low-Carbon Steel Joint Bars (A 3 – 49 T),
Structural Nickel Steel (A 8 – 52a T),
Soft Steel Track Spikes (A 65 – 49 T),
Steel Screw Spikes (A 66 – 49 T),
Structural Silicon Steel (A 94 – 52 T),
Structural Steel for Locomotives and Cars (A 113 – 52 T),
Carbon Steel Forgings for General Industrial Use (A 235 – 52 T),
Alloy Steel Forgings for General Industrial Use (A 237 – 52 T),
Carbon and Alloy Steel Ring and Disk Forgings (A 243 – 51 T),
Carbon Steel Seamless Drum Forgings (A 266 – 51 T),
Low and Intermediate Tensile Strength Carbon-Steel Plates of Structural Quality (Plates 2 in. and Under in Thickness) (A 283 – 52 T),
Carbon and Alloy Steel Forgings for Magnetic Retaining Rings for Turbine Generators (A 288 – 50 T),
Alloy Steel Forgings for Nonmagnetic Coil Retaining Rings for Turbine Generators (A 289 – 52 T),

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[4] The proposed revision was accepted by the Society and the methods as revised appear in the 1954 Supplement to Book of ASTM Standards, Part 1.

Carbon and Alloy Steel Forgings for Rings for Reduction Gears (A 290 – 52 T),
Steel Sheet Piling (A 328 – 52 T),
Heat-Treated Steel Tires (A 329 – 50 T),
Tentative Method of Macroetch Testing and Inspection of Steel Forgings (A 317 – 52 T).

The committee recommends that the following eight tentatives be approved for reference to letter ballot of the Society for adoption as standard with revision as indicated:

Tentative Specifications for Medium-Carbon Steel Joint Bars (A 4 – 49 T):[1]

Section 8.—In Paragraphs (*a*) and (*b*) change the requirement for the diameter of the pin for the bend test from the present "equal to twice. . . ." to read "not greater than two times. . . ."

Tentative Specification for Carbon Steel Forgings for Locomotives and Cars (A 236 – 52 T):[1]

Title.—Change to read "Carbon Steel Forgings for Railway Use."

Section 1(a).—Change to read as follows:

> (*a*) This specification covers untreated and heat treated carbon steel forgings for railway use.
>
> NOTE.—When axles corresponding to the size classifications shown in Table II of the Tentative Specification for Carbon Steel Axles for Cars and Tenders (ASTM Designation: A 21)[3] are ordered heat treated in accordance with the note in Section 1 of Specification A 21, Sections 10, 11, 13, and 14 of Specification A 21 are applicable thereto.

Section 9.—In the second sentence change the word "ingot" to read "specimen" to permit the use of spectrographic analysis.

Tentative Specification for Alloy Steel Forgings for Locomotives and Cars (A 238 – 49 T):[1]

Title.—Change the words "Locomotives and Cars" to read "Railway Use."

Section 1(a).—Change to read: "This specification covers heat treated alloy steel forgings for railway use."

Tentative Specification for Carbon Steel Blooms, Billets, and Slabs for Forgings (A 273 – 52 T):[1]

Table I.—Revise footnote *b* to read: "For acid open-hearth steel, the maximum phosphorus and sulfur contents shall be 0.05 per cent."

Section 7.—In Paragraph (*b*) revise the words "samples shall be selected to represent the heat as fairly as possible" to read "samples selected to represent the heat as fairly as possible shall be taken."

Delete Paragraph (*d*).

Reletter Paragraph (*e*) as Paragraph (*d*) and revise to read as follows retaining the present tabular material: "When chips are taken by drilling, the approximate diameter of the drill used shall be as follows:"

Section 11.—Revise to read: "The heat number shall be marked or stamped on a side near the end, or on the end when practicable. When the material is bundled, the heat number shall be marked on a tag attached to the bundle."

Section 12(a).—Revise the last sentence to read: "All tests (except check analysis) and inspection shall be made at the place of manufacture prior to shipment, unless otherwise specified, and shall be so conducted as not to interfere unnecessarily with the operation of the works."

Supplementary Requirement S3.—Change the title from "Specified Maximum Incidental Alloying Elements" to read "Incidental Alloy Content."

Tentative Specification for Alloy Steel Blooms, Billets, and Slabs for Forgings (A 274 – 52 T):[1]

Section 2.—Revise to read: "The steel shall be made by the open-hearth or electric-furnace process."

Table I.—Revise footnote *c* to read as indicated above for footnote *b* in Specification A 273.

Section 7(b).—Revise the tabular

matter to read the same as in Section 7 (*b*) of Specification A 273, as follows:

Lots	Number of Pieces
15 tons or less	4
Over 15 tons	6

Section 11.—Revise as indicated above for Section 11 in Specification A 273.

Section 12(a).—Revise as indicated above for Section 12 (*a*) in Specification A 273.

Tentative Specifications for Carbon and Alloy Steel Forgings for Pinions for Reduction Gears (A 291 – 52 T):[1]

TABLE II.—CHANGES IN TENSILE REQUIREMENTS FOR SPECIFICATION A 291.

Class	Size, in.		Tensile Strength, min, psi		Yield Point, min, psi	
	Over	Not Over	Present	Change to	Present	Change to
4	...	10	125 000	120 000	100 000	95 000
	10	20	125 000	117 000	100 000	92 000
	20	...	125 000	115 000	100 000	90 000
5	...	10	140 000	140 000	115 000	115 000
	10	20	140 000	135 000	115 000	110 000
	20	...	140 000	130 000	115 000	105 000
6	...	10	145 000	145 000	120 000	120 000
	10	20	145 000	140 000	120 000	115 000
	20	...	145 000	135 000	120 000	110 000
8	...	10	185 000	185 000	160 000	155 000

Table III.—Revise the tensile requirements for classes 4, 5, 6, and 8 as shown in the accompanying Table II.

Tentative Specification for Carbon and Alloy Steel Forgings for Turbine Generator Rotors and Shafts (A 292 – 52 T):[1]

Table III.—Add a new footnote referenced after the yield strength requirements for classes 1 to 7, incl., to read: "In classes 1 to 7, incl., an alternate method of measuring yield strength may be employed, by which the yield strength is determined at 0.2 per cent offset; in this case 5000 psi is to be added to the requirements for yield strength in the above table."

Tentative Specification for Carbon and Alloy Steel Forgings for Turbine Bucket Wheels (A 294 – 52 T):[1]

Table III.—Add a new footnote referenced after the yield strength requirements for all classes to read the same as outlined above for the new footnote for Table III in Specification A 292, without limitation as to class of forging.

Revisions of Standards, Immediate Adoption

The committee recommends that the following five standards be revised as indicated and accordingly requests the necessary nine-tenths affirmative vote at the Annual Meeting in order that these may be referred to letter ballot of the Society:

Standard Specifications for High-Carbon Steel Joint Bars (A 5 – 53):[2]

Section 9.—In Paragraphs (*a*) and (*b*) change the requirement for the diameter of the pin for the bend test from the present "equal to three times. . . ." to read "not greater than three times. . . ."

Standard Specifications for Multiple-Wear Wrought Steel Wheels (A 57 – 48):[1]

Standard Specifications for One-Wear Wrought Steel Wheels (A 186 – 46):[1]

The revisions recommended in these specifications are quite voluminous and are being recommended in order to bring the requirements into conformance with the corresponding requirements of the AAR specifications. The proposed revisions are appended.[5]

Standard Specifications for Seamless and Welded Austenitic Stainless Steel Tubing (A 269 – 52):[1]

Table II.—Add a new footnote reference after "Permissible Variations in Cut Length, in." to read as follows: "These tolerances apply to cut lengths up to and including 24 ft. For lengths over 24 ft an additional over tolerance of $\frac{1}{8}$ in. for each 10 ft or fraction thereof shall be permissible, up to a maximum tolerance of $\frac{1}{2}$ in."

Standard Specifications for Seamless Austenitic Chromium-Nickel Steel Still Tubes for Refinery Service (A 271 – 53):[2]

Table II.—Add the following permissible variations in dimensions and weight for tubes over $7\frac{1}{2}$ to 9 in., incl., in outside diameter:

Outside diameter, in.	Over	$\frac{1}{64}$
	Under	$\frac{1}{16}$
Specified wall thickness, per cent	Over	22
	Under	0
Calculated weight per ft, per cent	Over	5
	Under	5
Cut length, in.	Over	$\frac{3}{16}$
	Under	0

Table III.—Add the following plug gage formula for tubes over $7\frac{1}{2}$ to 9 in., incl., in outside diameter:

$$PG = D - \frac{2t}{0.90} - 0.090$$

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[5] The proposed revisions were accepted by the Society and the specifications as revised appear in the 1954 Supplement to Book of ASTM Standards, Part 1.

REPORT OF COMMITTEE A-3
ON
CAST IRON*

Committee A-3 on Cast Iron held meetings on July 2, 1953, in Atlantic City, N. J., and on February 4, 1954, in Washington, D. C.

At the present time, the committee consists of 119 members, of whom 43 are classified as producers, 49 as consumers, and 27 as general interest members.

The committee records with regret the death of C. O. Burgess the early part of this year. Mr. Burgess was vice-chairman of Committee A-3 at the time of his death and served effectively on many of the subcommittees as well as serving as secretary from 1944 to 1949.

Mr. W. F. Abercrombie, Engineer of Materials and Tests, State Highway Department of Georgia, has been appointed chairman of Subcommittee VIII on Cast Iron Culvert Pipe.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, H. W. Stuart.
Vice-Chairman, D. E. Krause.
Secretary, T. E. Eagan.

NEW TENTATIVE

The committee recommends for publication as tentative the Specifications for Cast Iron Pressure Pipe as appended hereto.[1] These specifications make reference to the specifications developed by ASA Sectional Committee A21 on Cast Iron Pipe and Fittings, which committee is under the sponsorship of the AGA, ASTM, AWWA, and the New England Water Works Assn.

ADOPTION OF TENTATIVE AS STANDARD

The committee recommends that the Tentative Methods of Impact Testing of Cast Iron (**A 327 – 50 T**)[2] be approved for reference to letter ballot of the Society for adoption as standard without change.

WITHDRAWAL OF STANDARD

The committee recommends the withdrawal of Standard Specifications for Cast Iron Pit-Cast Pipe for Water or Other Liquids (**A 44 – 41**).[2] This standard is being replaced by the above proposed new tentative specification.

TENTATIVES CONTINUED WITHOUT REVISION

The committee recommends that the following specifications be continued as tentative without revision:

Tentative Specifications for:

Foundry Pig Iron (A 43 – 49 T),
Chilled and White Iron Castings (A 360 – 52 T), and
Nodular Iron Castings (A 339 – 51 T).

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[3]

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13–18, 1954.

[1] The new tentative was accepted by the Society and appears in the 1954 Supplement to Book of ASTM Standards, Part 1.

[2] 1952 Book of ASTM Standards, Part 1.

[3] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

ACTIVITIES OF SUBCOMMITTEES

A complete review of subcommittee activities will not be given, but only those which have a direct bearing on present specifications or those which may be of interest to other committees.

Subcommittee I on Pig Iron (H. W. Stuart, chairman) is attempting to reach an agreement on certain revisions of Specifications A 43 - 49 T so the specifications can be recommended for adoption as standard. The principal difficulty in obtaining agreement on the revisions concerns the limits of silicon content of foundry pig iron.

Subcommittee XV on Impact Testing (J. T. MacKenzie, chairman) has reported that no comments were received in regard to Methods A 327 - 50 T and they were therefore recommended for adoption as standard.

Subcommittee XVI on Heat Treatment of Cast Iron (V. T. Malcolm, chairman) is obtaining data on effect of using stress relieving temperatures above 1050 F as specified in Specification A 278.

Subcommittee XIX on Chilled and White Iron Casting (J. J. Marsalka, chairman) could not reach agreement on the adoption of the Specifications A 360 - 52 T to standard so they will be continued as tentative. An acceptable method of measuring the depth of chill has not as yet been found.

Subcommittee XXII on Elevated Temperature Properties of Cast Iron (J. S. Vanick, chairman) has requested and received size B test bars conforming to Specification A 278 for evaluation at Southern Research Institute as part of Project SP2 of the Joint Committee on Effect of Temperature on the Properties of Metals.

Subcommittee XXIV on Nodular Iron (T. E. Eagan, chairman) discussed revision of Specifications A 339 - 51 T, particularly with respect to an increase in elongation requirements for the annealed grade of nodular iron, but differences in viewpoints resulted in a decision to retain these specifications as tentative. Reports indicate that this material is being made with an increasing degree of uniformity of properties.

Subcommittee XXVI on Low Temperature Properties of Cast Iron (R. W. Kraft, chairman) held its first meeting on February 3, 1954, in Washington, D. C. The need for specifications for low temperature applications was discussed, but it was felt that more data on the effect of low temperatures on cast iron are needed before much can be done.

This report has been submitted to letter ballot of the committee, which consist of 119 voting members; 62 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

J. S. VANICK,
Chairman.

D. E. KRAUSE,
Secretary.

REPORT OF COMMITTEE A-5

ON

CORROSION OF IRON AND STEEL*

Committee A-5 on Corrosion of Iron and Steel held two meetings during the year: on July 2, 1953, at Atlantic City, N. J., and on February 3, 1954, at Washington, D. C.

The committee now consists of 111 members, of whom 49 are classified as producers, 35 as consumers, and 27 as general interest members.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, A. P. Jahn.
First Vice-Chairman, J. G. Thompson.
Second Vice-Chairman, E. F. Lundeen.
Secretary, C. P. Larrabee.

REVISION OF TENTATIVES

The committee recommends that the following specifications be revised as indicated and continued as tentative:

Tentative Specifications for Zinc-Coated Steel Wire Strand ("Galvanized" and Class A ("Extra Galvanized")) (**A 122 - 52 T**).[1]

Section 1.—Delete the words "electrical conductors, overhead ground wires." Add the following additional note: "NOTE.—Zinc-coated steel overhead ground wire strand is covered by the Tentative Specifications for Zinc-Coated Steel Overhead Ground Wire Strand (ASTM Designation: A 363)."

Section 9.—Delete this section and renumber subsequent sections.

Table II.—Delete this table and renumber subsequent tables.

Section 10(b).—Delete this section.

Tentative Specifications for Zinc-Coated Steel Wire Strand (Class B and Class C Coatings) (**A 218 - 52 T**).[1]

Section 1.—Delete the words "electrical conductors, overhead ground wires." Add the following additional note: "NOTE.—Zinc-coated steel overhead ground wire strand is covered by the Tentative Specifications for Zinc-Coated Steel Overhead Ground Wire Strand (ASTM Designation: A 363)."

Table II.—Delete this table and renumber subsequent tables.

Section 9.—Delete this section and renumber subsequent sections.

Section 10(b).—Delete this section.

The revision in Section 1 is recommended since the products specified in Specifications A 122 and A 218 are not designed for use as electrical conductors and because Specifications A 363 provide for a product to be used as overhead ground wire strand.

The remainder of the revisions are recommended in order to delete from these specifications the requirements for Uniformity of Coating and all reference to the Preece Test. Uniformity of Coating (Preece Test) requirements have been omitted from various recent ASTM specifications for zinc-coated wire. Several large users of such wire have removed the Uniformity of Coating requirements from their own specifications. The shortcomings of this particular test when applied to wire are well known and, following a ballot in the subcommittee, the committee voted on the above recommendation in 1952. The letter ballot vote at that time was as follows:

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13-18, 1954.

[1] 1952 Book of ASTM Standards, Part 1.

Classification	A-5 Membership	Affirmative	Negative
Producers	53	24	3
Consumers	36	16	4
General Interest	29	11	3
Total	118	51	10

The negative vote in this case was so large that the matter was held a year for review at subsequent meetings. At the 1953 Society meeting, a paper entitled "Some Observations on the Preece Test and Stripping Tests for Zinc-Coated Wires" was presented as an appendix to the annual report of the committee.[2] The negative votes, in summary, claim that the Preece Test has some merit and that no replacing test has been proposed or developed. There seems no chance of resolving these negative votes, and the committee now recommends action in accordance with the majority vote of the committee.

ADOPTION OF TENTATIVE AS STANDARD

The committee recommends that the Tentative Methods of Test for Local Thickness of Electrodeposited Coatings (**A 219 - 51 T**)[1] be approved for reference to letter ballot of the Society for adoption as standard without change. This recommendation is made jointly with Committee B-8 on Electrodeposited Metallic Coatings.

REVISION OF STANDARD, IMMEDIATE ADOPTION

The committee recommends for immediate adoption revisions as appended hereto[3] of the Standard Method of Test for Weight and Composition of Coating on Long Terne Sheets by the Triple Spot Test (**A 309 - 49**),[1] and accordingly asks for the necessary nine-tenths affirmative vote at the Annual Meeting in order that the revisions may be referred to letter ballot of the Society.

AMERICAN STANDARDS

In accordance with ASTM policy, Committee A-5 this year examined the standards under its jurisdiction as regards their suitability for submission to the American Standards Association for approval as American Standard. Committee A-5 accordingly recommends that the following specifications be submitted to ASA for approval as American Standard:

Specifications for:

Zinc-Coated (Galvanized) Iron or Steel Sheets, Coils and Cut Lengths (A 93 - 53 T),
Zinc-Coated (Galvanized) "Iron" Telephone and Telegraph Line Wire (A 111 - 52),
Zinc-Coated Steel Wire Strand ("Galvanized" and Class A ("Extra Galvanized")) (A 122 - 52 T),[4]
Zinc (Hot-Galvanized) Coatings on Products Fabricated from Rolled, Pressed, and Forged Steel Shapes, Plates, Bars, and Strip (A 123 - 53),
Zinc Coating (Hot-Dip) on Iron and Steel Hardware (A 153 - 53),
Zinc-Coated Steel Wire Strand (Class B and Class C Coatings) (A 218 - 52 T)[4], and
Zinc-Coated (Galvanized) High Tensile Steel Telephone and Telegraph Line Wire (A 326 - 52).

Methods of Test for:

Weight of Coating on Zinc-Coated (Galvanized) Iron or Steel Articles (A 90 - 53).

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[2] *Proceedings*, Am. Soc. Testing Mats., Vol. 53, p. 125 (1953).

[3] The revised standard was accepted by the Society and appears in the 1954 Supplement to Book of ASTM Standards, Part 1.

[4] Further revisions of these specifications are recommended as set forth elsewhere in this report, and the specifications as presented for approval as American Standard should include the latest revision.

Recommended Practice for:

- Safeguarding Against Embrittlement of Hot Galvanized Structural Steel Products and Procedure for Detecting Embrittlement (A 143 – 46).

Several of these standards at one time had approval as American Standard but the approval lapsed since subsequent revisions were not presented to the ASA

The committee recommends that the following standards, which carry approval as American Standard, be presented to the ASA for reaffirmation:

Specifications for:

- Zinc-Coated (Galvanized) Iron or Steel Farm-Field and Railroad Right-of-Way Wire Fencing (A 116 – 48),
- Zinc-Coated Iron or Steel Chain-Link Fence Fabric Galvanized After Weaving (A 117 – 33), and
- Zinc-Coated (Galvanized) Iron or Steel Barbed Wire (A 121 – 48).

CONTINUATION OF TENTATIVES WITHOUT REVISION

The committee recommends that the following be continued as tentative without revision:

Tentative Specifications for:

- Zinc-Coated (Galvanized) Iron or Steel Sheets, Coils and Cut Lengths (A 93 – 53 T),
- Long Terne Iron or Steel Sheets, Coils and Cut Lengths (A 308 – 53 T),
- Zinc-Coated Iron or Steel Chain-Link Fence Fabric Galvanized Before Weaving (A 337–51 T),
- 1.25 oz Ordered Coating (Pot Yield) Zinc-Coated (Galvanized) Iron or Steel Roofing Sheets (A 361 – 52 T), and
- Zinc-Coated Steel Overhead Ground Wire Strand (A 363 – 52 T).

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[5]

ACTIVITIES OF SUBCOMMITTEES

Subcommittee VII on Methods of Test (O. B. Ellis, chairman) completed its work on the revision of Standard Method of Test for Weight and Composition of Coating on Long Terne Sheets by the Triple Spot Test (A 309 – 49), which revision is referred to earlier in this report. The subcommittee is investigating nondestructive methods for the determination of thickness of metallic coating.

Subcommittee XI on Sheet Specifications (E. F. Lundeen, chairman) is actively engaged in the study of specifications under its jurisdiction and has recommended the continuance as tentative without change at this time of Specifications A 93 – 53 T, A 308 – 53 T, and A 361 – 52 T, which recommendation is referred to earlier in the report.

Subcommittee XII on Wire Specifications (J. F. Occasione, chairman) prepared the revisions referred to earlier in the report of Standard Specifications for Zinc-Coated (Galvanized) Steel Tie Wires (A 112 – 33), Tentative Specifications for Zinc-Coated Steel Wire Strand (Galvanized and Class A) (A 122 – 52 T), and Tentative Specifications for Zinc-Coated Steel Wire Strand (Class B and Class C Coatings) (A 218 – 52 T). The subcommittee is working on a revision of Tentative Specifications for Overhead Ground Wire Strand (A 363 – 52 T) and of Tentative Specifications for Zinc-Coated Iron or Steel Chain-Link Fence Fabric Galvanized Before Weaving (A 337 – 51 T). Work is being done on the preparation of specifications for zinc-coated low carbon steel armor wire, for zinc-coated poultry netting, and for zinc-coated welded steel fabric.

Subcommittee XIII on Hardware Specifications (B. J. Barmack, chairman) has in progress the preparation of tentative specifications for zinc-coating

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[5] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

(hot-dip) on fabricated or assembled steel products, a recommended practice for safeguarding against warpage and distortion during hot-dip galvanizing of steel assemblies, and recommended shop practices and design suggestions for safeguarding against inferior galvanized coating.

Subcommittee XIV on Sheet Tests (C. P. Larrabee, chairman) has summarized the sheet inspection data to date in the report appended hereto.[6]

Subcommittee XV on Wire Tests (F. M. Reinhart, chairman) appends hereto its report of inspection data.[7]

Subcommittee XVI on Hardware Tests (A. Mendizza, chairman) is continuing with its plans for a new test on hardware.

This report has been submitted to letter ballot of the committee, which consists of 111 members; 89 members returned their ballots, of whom 80 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

A. P. Jahn,
Chairman.

C. P. Larrabee,
Secretary.

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[6] See p. 110.

[7] See p. 123.

REPORT OF SUBCOMMITTEE XIV ON INSPECTION OF BLACK AND GALVANIZED SHEETS

The annual inspections of the sheet tests at Annapolis, Md., Altoona, Pa., and State College, Pa., were made during April, 1953 and 1954. The Altoona and State College inspections were made in April of 1954, but the Annapolis inspection was held in March. The earlier inspection at Annapolis was made at the request of the U. S. Naval Engineering Experiment Station through whose courtesy these specimens have been exposed since 1916. The site presently occupied by these tests is needed due to present expansion plans. It has been decided that the importance of future data would not warrant the expenditure of the $1500 estimated as the cost of moving the specimens to another location, and by vote of both Committee A-5 and the Advisory Committee on Corrosion the test has been discontinued and the sheets scrapped. The discontinuation of the Annapolis site marks the end of the copper-bearing and non-copper-bearing sheet tests begun in 1916, the Fort Sheridan, Ill., and Pittsburgh, Pa., sites having been abandoned in 1928 and 1923, respectively.

Annapolis, Md.:

The failures to date in the 16-gage uncoated sheets exposed in 1916 at Annapolis are shown in Table I. Attention is directed to the fact that after 37.5 yr, only 23 sheets out of a total of 258 have been found to have visible perforations. The final results of the 22-gage test were published in the Society's *Proceedings* in 1952[1] and are reproduced herein (Table IV).

TABLE I.—RECORDS OF FAILURES AT ANNAPOLIS OF NO. 16-GAGE UNCOATED SHEETS[a] BY CLASSES.

Class	Groups	Sheets	Failed	Average Life of Failed Sheets, years
Open-hearth Iron (low copper)	3	47	13	35.0
Open-hearth Steel (low copper)	3	33	1	32.5
Bessemer Steel (low copper)	2	20	7	30.5
Wrought Iron (low copper)	1	3	1	34.5
Wrought Iron (copper)	1	12	1	28
		115	23	

[a] With the exception of the one wrought iron sheet shown, none of the 143 sheets in groups that have medium (0.06 to 0.12 per cent) or over 0.2 per cent copper has failed.

Altoona, Pa.:

The complete inspection results of the test of galvanized and uncoated steel sheets, exposed in 1926, are shown in Table II. One sheet was found perforated at the 1953 inspection and 0 at the 1954 inspection. The yearly inspection will be continued until both the 22-gage sheets have failed, at which time the test will be abandoned. It is not believed worth-while to continue the test until the ten 16-gage sheets, which had 2.5-oz coatings, become perforated.

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[1] Report of Subcommittee XIV, *Proceedings*, Am. Soc. Testing Mats., Vol. 52, p. 111 (1952).

State College, Pa.:

The complete inspection results (1926 to date), including three omissions from the 1952 Table, are given in Table III. It is noteworthy that none of the 28-gage (about 0.016-in. thick) sheets, originally having 0.75 oz per sq ft (0.00063 in. zinc each side) of coating, have become perforated after 28 yr. Six of the 10 uncoated 22-gage sheets have perforated.

TABLE II.—LIFE OF CORRUGATED GALVANIZED AND BLACK SHEETS, 26 BY 30 IN.
Exposed at Altoona, Pa., on April 22, 1926.

Sheet[c]	No. 16 Gage, 2.5 oz per sq ft[a]		No. 22 Gage, 2.5 oz per sq ft[a]			No. 22 Gage, 2.0 oz per sq ft[a]			No. 22 Gage, 1.5 oz per sq ft[a]			No. 22 Gage, 1.25 oz per sq ft[a]			No. 22 Gage, 0.75 oz per sq ft[a]			No. 28 Gage, 0.75 oz per sq ft[a]			No. 22 Gage, Un-coated
	Years To		Years To			Years To			Years To			Years To			Years To			Years To			
	1st Rust	100 per cent Rust	1st Rust	100 per cent Rust	Perforation	1st Rust	100 per cent Rust	Perforation	1st Rust	100 per cent Rust	Perforation	1st Rust	100 per cent Rust	Perforation	1st Rust	100 per cent Rust	Perforation	1st Rust	100 per cent Rust	Perforation	Years To Perforation
R (T)[d]	....	....	4.3	12.0	21.0	3.3	9.5	18.5	3.3	5.0	14.5	2.3	4.3	14.5	....	....	....	....	....	....	4.3
(B)[d]			4.5	11.5	21.5	3.3	9.0	16.5	3.3	7.0	17.0	2.3	4.5	16.0							
V (T)	4.3	11.0	4.3	9.0	[b]	3.3	7.0	17.5	2.3	7.0	14.5	2.3	5.2	13.5	1.4	3.3	9.0	....	....	....	4.3(V)
(or U) (B)	4.3	7.0	4.8	9.0	17.5	4.3	6.8	19.0	2.5	7.0	15.0	2.3	4.5	15.0	2.3	3.3	13.0				4.3(U)
N (T)	....	....	4.3	8.5	22.5	3.3	8.5	20.0	3.3	5.5	17.0	2.3	4.5	15.0	1.4	2.8	13.0	2.0	3.3	7.0	7.5
(B)			3.5	12.0	24.0	3.5	8.0	22.0	3.3	5.9	19.0	2.3	4.5	[b]	1.4	3.3	15.0	2.3	3.3	11.0	
T (T)	4.5	10.5	5.5	11.5	22.5	3.5	7.5	20.0	2.3	5.0	18.5	2.3	5.0	15.0	1.4	2.8	13.5	2.0	2.8	9.0	8.5
(B)	4.8	9.0	6.3	11.5	•	3.5	7.0	22.0	2.5	5.2	17.0	2.3	4.3	17.0	2.3	3.0	15.0	2.3	3.3	11.0	
Y (T)	4.3	11.5	3.5	11.5	....	3.3	8.5	....	2.5	5.0	....	2.3	3.3	....	2.3	3.5	....	1.4	3.5	....	....
(B)	4.5	13.7	3.3	9.5	....	4.3	9.0	....	3.3	5.2	....	2.5	4.3	....	2.3	3.3	....	2.3	3.3	....	
S (T)	4.3	12.0	4.3	12.0	22.0	4.3	8.5	20.5	3.0	4.5	19.0	2.3	4.0	17.0	2.0	2.8	13.5	2.0	3.0	7.0	9.0
(B)	4.3	12.5	4.8	14.5	24.0	4.3	8.5	23.0	3.3	6.3	20.5	3.0	4.3	19.0	2.3	2.8	15.0	2.3	3.0	10.5	
C (T)	....	....	4.0	10.5	26.0	3.3	8.5	22.5	2.5	6.5	21.5	2.3	4.5	19.0	1.4	3.5	[b]	....	....	....	
(B)			5.8	13.5	26.0	4.3	10.0	24.0	3.3	6.5	19.0	2.5	4.3	19.5	1.4	3.0	[b]				
K (T)	4.3	12.5	4.3	11.5	25.0	4.3	7.5	24.0	3.3	5.2	21.5	2.5	4.3	[b]	2.3	3.0	[b]	2.3	2.8	10.5	13.0
(B)	4.3	11.5	4.5	11.5	•	4.3	8.5	27.0	3.3	5.0	25.0	3.3	4.3	21.0	2.3	3.0	21.0	2.3	3.0	10.5	
W (T)	....	....	5.2	10.5	21.5	3.5	6.5	19.0	3.3	5.0	15.0	2.3	4.0	14.5	....	....	....	....	....	....	5.0
(B)			5.2	12.0	23.0	4.3	7.5	19.5	3.3	5.5	17.0	2.3	4.0	15.0							
Average	4.4	11.1	4.6	11.2	....	3.8	8.1	....	3.0	5.7	....	2.4	4.3	....	1.9	3.1	....	2.1	3.1	....	

• Data not yet available.

[a] Coating weight is "oz per sq ft" of sheet (both sides).

[b] Blown away or discarded due to mechanical damage.

[c] Compositions of individual materials given in 1927 *Proceedings.*

[d] From 1927 *Proceedings.* "T" refers to the front end of sheet as it went through the galvanizing pot, "B" refers to the back end.

DISCUSSION OF RESULTS TO DATE

By vote of Committee A-5, Subcommittee XIV was instructed to include in this year's report a condensed summary of the conclusions that could logically be drawn from the atmospheric corrosion tests installed by the Subcommittee in 1916 and in 1926.

Tests Exposed in 1916:

These tests at Annapolis, Md., Fort Sheridan, Ill., and Pittsburgh, Pa., consisted of steel sheets from which the rolling scale had been removed by acid pickling. The complete details on these sheets were given in the 1918 *Proceedings*, and the final results are shown as Tables IV, V, and VI. In spite of the necessity of discontinuing the tests at these sites before *all* sheets had failed, the combined data and calculations from these three tests, Tables VII, VIII, and IX, justify the following:

TABLE III.—LIFE OF CORRUGATED GALVANIZED AND BLACK SHEETS, 26 BY 30 IN.
Exposed at State College, Pa., on April 23, 1926.

Sheet	No. 16 Gage, 2.5 oz per sq ft[a]		No. 22 Gage, 2.5 oz per sq ft[a]			No. 22 Gage, 2.0 oz per sq ft[a]			No. 22 Gage, 1.5 oz per sq ft[a]			No. 22 Gage, 1.25 oz per sq ft[a]			No. 22 Gage, 0.75 oz per sq ft[a]			No. 28 Gage, 0.75 oz per sq ft[a]			No. 22 Gage, Un-coated
	Years To		Years To			Years To			Years To			Years To			Years To			Years To			
	1st Rust	100 per cent Rust	1st Rust	100 per cent Rust	Perforation	1st Rust	100 per cent Rust	Perforation	1st Rust	100 per cent Rust	Perforation	1st Rust	100 per cent Rust	Perforation	1st Rust	100 Per cent Rust	Perforation	1st Rust	100 per cent Rust	Perforation	Years To Perforation
R (T)	24.0	*	26.0	*	*	19.0	*	*	17.5	*	*	14.5	*	*	....	....	....	....	....	....	26.0[b]
(B)	27.0	*	*	*	*	20.0	*	*	16.5	*	*	15.0	*	*							
V (T)	27.0	*	21.5	*	*	18.5	*	*	16.0	*	*	15.0	*	*	9.5	23.0	*				24.0(V)
(or U) (B)	24.0	*	*	*	*	25.0	*	*	15.5	*	*	16.5	*	*	10.5	24.0	*	....	....	....	25.0(U)[b]
N (T)	....	....	20.5	*	*	22.5	*	*	17.5	*	*	12.0	*	*	6.5	20.5	*	11.0	23.0	*	28.0
(B)			28.0	*	*	22.5	*	*	15.5	*	*	13.5	*	*	9.0	23.0	*	11.5	*	*	
T (T)	27.0	*	*	*	*	21.0	*	*	16.0	*	*	15.0	*	*	9.0	26.0	*	9.0	24.0	*	*
(B)	*	*	28.0	*	*	23.0	*	*	14.5	*	*	13.5	*	*	10.5	22.5	*	12.0	25.0	*	
Y (T)	21.5	*	22.5	*	....	19.5	*	....	17.5	*	....	14.5	*	....	10.0	22.5	....	9.5	24.0	....	25.0[b]
(B)	22.5	*	*	*	....	19.0	*	....	18.5	*	....	14.5	*	....	10.5	*	....	13.0	26.0	....	
S (T)	22.0	*	28.0	*	*	25.0	*	*	19.0	*	*	14.5	*	*	10.5	21.5	*	11.5	22.0	*	*
(B)	22.5	*	28.0	*	*	28.0	*	*	19.5	*	*	15.5	*	*	11.0	21.5	*	11.5	21.5	*	
C (T)	....	....	22.5	*	*	17.5	*	*	16.0	*	*	14.5	*	*	9.5	24.0	*	....	....	....	*
(B)			*	*	*	21.5	*	*	18.5	*	*	14.5	*	*	10.0	24.0	*				
K (T)	23.0	*	25.0	*	*	22.5	*	*	17.5	*	*	14.5	*	*	11.5	24.0	*	10.5	23.0	*	*
(B)	24.0	*	*	*	*	28.0	*	*	21.0	*	*	16.5	*	*	11.5	22.5	*	11.5	21.0	*	
W (T)	....	....	*	*	*	25.0	*	*	16.5	*	*	13.5	*	*	....	....	....	....	....	....	27.0
(B)			*	*	*	28.0	*	*	15.0	*	*	14.5	*	*							
Average	....	....		....	....	22.5	....	....	17.0	....	....	14.6			10.0			11.1			

* Data not yet available.

[a] Coating weight is "oz per sq ft" of sheet (both sides).

[b] Inadvertently omitted from 1952 report.

1. Sheets of open-hearth iron, open-hearth steel, bessemer steel, and wrought iron (hand puddled) with copper contents of about 0.2 per cent remained unperforated longer than similar grades with residual copper contents below 0.04 per cent.

2. The beneficial effect of both copper and phosphorus upon the atmospheric corrosion resistance of steels was demonstrated by the longer life of the higher phosphorus materials (bessemer copper steel and open-hearth steel (acid)).

3. The benefit of copper does not cease at comparatively low values (0.1 per cent). A study of the detailed results in Tables IV, V, and VI shows that steels having about 0.2 (or over) per cent copper had longer lives at each location than similar type steels with 0.1 per cent copper.

4. Considering open-hearth iron, open-hearth steel, and bessemer steel, the copperized materials had 1.7, 2.5, and 2.9 times the lives of the residual-copper (less than 0.05 per cent) materials at Annapolis, Fort Sheridan, and

TABLE IV.—RECORD OF FAILURES AT ANNAPOLIS OF 22-GAGE COPPER-BEARING AND NON-COPPER-BEARING CORRUGATED BLACK SHEETS.

Sheets Exposed October 17, 1916. Inspections Made Semiannually from 1917 to 1951.

Group	Designation	Series	Average Analysis, per cent						Number of Sheets in Test[a]	Life of Each Failed Sheet, yr																Number of Sheets in Test	Number of Sheets Failed	Average Life of Sheets, yr	Group
			Carbon	Manganese	Phosphorus	Sulfur	Silicon	Copper																					
Z......	Open-hearth Steel	B	0.032	0.32	0.063	0.042	.....	0.019	3	13.5	17.0	19.0	...	...	...	...	...	...	...	...	...	...	...	...	...	3	3	16.5	Z
O......	Open-hearth Steel	A	0.121	0.536	0.008	0.030	0.249	0.020	12	7.0	9.0	9.0	9.0	9.0	9.5	10.0	10.0	11.0	11.0	13.0	17.0	...	...	...	...	12	12	10.4	O
B......	Open-hearth Steel	A	0.09	0.38	0.017	0.062	0.036	0.084	3	20.0	20.5	24.0	...	...	...	...	...	...	...	...	...	...	...	...	...	3	3	21.5	B
M......	Open-hearth Steel	B	0.093	0.419	0.013	0.041	0.011	0.185	13	20.0	20.5	23.5	23.5	23.5	24.0	24.0	24.0	24.0	24.0	24.0	24.0	25.0	...	...	...	13	13	23.4	M
B......	Open-hearth Steel	A	0.06	0.27	0.014	0.053	0.006	0.187	9	19.5	20.0	21.5	22.0	22.5	23.0	26.0	28.0	28.5	...	...	...	...	...	...	...	9	9	23.4	B
Z......	Open-hearth Steel	B	0.067	0.351	0.045	0.052	0.003	0.187	3	27.0	27.5	28.0	...	...	...	...	...	...	...	...	...	...	...	...	...	3	3	27.5	Z
T......	Open-hearth Steel	B	0.083	0.313	0.009	0.020	0.005	0.227	14	19.5	19.5	19.5	21.5	21.5	21.5	23.0	23.5	23.5	23.5	24.0	24.0	24.0	24.0	...	...	14	14	22.3	T
K......	Open-hearth Steel (Acid)	A	0.107	0.447	0.091	0.046	0.004	0.237	14	24.5	28.0	28.5	28.5	28.5	29.0	29.5	30.0	31.0	31.5	32.0	32.0	32.0	33.5	...	...	14	14	29.9	K
H......	Open-hearth Steel	A	0.069	0.387	0.016	0.027	0.004	0.244	10	19.5	21.0	21.5	23.0	23.5	23.5	23.5	24.0	24.0	25.0	...	...	...	...	...	...	10	10	22.9	H
Z......	Open-hearth Steel	B	0.065	0.35	0.050	0.059	0.003	0.264	2	24.5	28.0	...	...	...	...	...	...	...	...	...	...	...	...	...	...	2	2	26.3	Z
Z......	Open-hearth Steel	B	0.073	0.42	0.052	0.054	Trace	0.641	3	28.0	29.0	33.5	...	...	...	...	...	...	...	...	...	...	...	...	...	3	3	30.2	Z
S......	Open-hearth Iron	B	0.02	0.023	0.006	0.022	0.004	0.022	14	7.0	8.0	8.5	9.0	9.5	10.0	11.0	11.5	11.5	12.5	12.5	12.5	12.5	12.5	...	...	14	14	10.6	S
D......	Open-hearth Iron	A	0.02	0.026	0.004	0.022	0.002	0.024	6	16.0	16.0	16.0	19.5	19.5	23.5	...	...	...	...	...	...	...	...	...	...	6	6	18.4	D
X......	Open-hearth Iron	B	0.021	0.055	0.007	0.031	0.004	0.027	14	10.5	13.0	13.5	14.5	14.5	16.0	16.0	16.5	16.5	17.0	17.5	17.5	18.0	19.0	...	...	14	14	15.7	X
C......	Open-hearth Iron	A	0.01	0.028	0.002	0.027	0.002	0.141	3	17.5	20.5	23.5	...	...	...	...	...	...	...	...	...	...	...	...	...	3	3	20.5	C
C......	Open-hearth Iron	A	0.015	0.028	0.006	0.036	0.003	0.194	9	16.5	16.5	18.5	19.0	19.0	20.0	20.5	21.5	21.5	...	...	...	...	...	...	...	9	9	19.2	C
U......	Open-hearth Iron	B	0.017	0.074	0.008	0.037	0.005	0.260	13	15.5	16.5	19.0	19.0	19.0	19.0	19.0	19.5	20.0	20.0	21.0	21.0	22.5	...	...	...	13	13	19.3	U
V......	Open-hearth Iron	B	0.018	0.051	0.007	0.021	0.005	0.304	14	17.0	17.0	17.5	18.5	18.5	19.0	20.0	20.0	20.5	21.0	22.0	22.0	22.5	24.0	...	...	14	14	20.0	V
A......	Bessemer Steel	A	0.038	0.386	0.089	0.040	0.007	0.014	15	15.5	16.5	16.5	17.0	17.0	17.0	18.0	19.0	19.0	19.5	19.5	19.5	19.5	19.5	20.0	...	15	15	18.2	A
Z......	Bessemer Steel	B	0.063	0.41	0.102	0.044	0.009	0.013	3	11.5	11.5	11.5	...	...	...	...	...	...	...	...	...	...	...	...	...	3	3	11.5	Z
Z......	Bessemer Steel	B	0.077	0.44	0.095	0.036	0.003	0.140	3	27.5	27.5	27.5	...	...	...	...	...	...	...	...	...	...	...	...	...	3	3	27.5	Z
I......	Bessemer Steel	A	0.041	0.365	0.097	0.068	0.008	0.252	15	24.0	26.0	26.5	26.5	26.5	26.5	27.0	28.0	28.0	29.0	29.5	29.5	31.0	31.5	33.5	...	15	15	28.2	I
Z......	Bessemer Steel	B	0.058	0.37	0.093	0.043	0.009	0.269	3	28.0	29.5	31.0	...	...	...	...	...	...	...	...	...	...	...	...	...	3	3	29.5	Z
Z......	Bessemer Steel	B	0.055	0.38	0.110	0.046	.....	0.527	3	32.0	32.5	34.5	...	...	...	...	...	...	...	...	...	...	...	...	...	3	3	33.0	Z
Y......	Wrought Iron	B	0.03	0.055	0.139	0.021	0.218	0.020	3	18.0	19.5	23.5	...	...	...	...	...	...	...	...	...	...	...	...	...	3	3	20.3	Y
E. ...	Wrought Iron	A	0.033	0.034	0.114	0.021	0.134	0.283	10	19.5	20.5	21.0	21.0	23.0	23.0	23.0	23.0	24.0	25.0	...	...	...	...	...	...	10	10	22.3	E
							Total......		214																Total...	214	214		

---

[a] The number of sheets in the test indicated in this table is less than the number shown in earlier reports because certain sheets were discarded due to mechanical damage.

TABLE V.—RECORD OF FAILURES AT FORT SHERIDAN OF NO. 22-GAGE COPPER-BEARING AND NONCOPPER-BEARING CORRUGATED BLACK SHEETS.
Sheets Exposed April 9, 1917. Inspections Made Semiannually from 1917 to 1928. Rearrangement of Data from 1928 Report of Committee A-5, Subcommittee III[a]

Group[b]	Designation	Series	Average Analysis, per cent						Number of Sheets in Test	Life of Each Failed Sheet, yr.[e]								
			Carbon	Manganese	Phosphorus	Sulfur	Silicon	Copper										
Z 4	Open-hearth Steel	B	0.06	0.32	0.065	0.044	0.002	0.018	2	3.1	4.5 A	..	..	..	..	..	..	..
O	Open-hearth Steel	A	0.12	0.54	0.008	0.030	0.249	0.020	12	2.7	2.7	2.7	3.1 A	3.1	3.1	3.1	3.1	3.5 B
B 12[c]	Open-hearth Steel	A	0.02	0.23	0.012	0.055	0.004	0.112	11	11.0	11.0	11.0	11.0	11.0	11.0	11.0	•	•
M	Open-hearth Steel	B	0.09	0.42	0.013	0.041	0.011	0.185	14	11.0	11.0 A	•	•	•	•	•	•	•
B 9 and 11	Open-hearth Steel	A	0.06	0.27	0.014	0.053	0.006	0.156	2	•	•	..	..	..	..	..	..	..
Z 506[d]	Open-hearth Steel	B	0.06	0.36	0.045	0.053	..	0.174	2	•	•	..	..	..	..	..	..	..
Z 508[d]	Open-hearth Steel	B	0.06	0.36	0.052	0.064	..	0.247										
T	Open-hearth Steel	B	0.08	0.31	0.009	0.020	0.005	0.227	14	11.0	11.0	11.0	11.0	11.0	11.0 A	11.0 B	11.0 C	•
K	Open-hearth Steel (acid)	A	0.11	0.45	0.091	0.046	0.004	0.237	16	•	•	•	•	•	•	•	•	•
H	Open-hearth Steel	A	0.07	0.39	0.016	0.027	0.004	0.244	11	•	•	•	•	•	•	•	•	•
Z 6	Open-hearth Steel	B	0.06	0.39	0.047	0.047	..	0.286	2	•	•	.	..	..	..	..	..	..
Z 7	Open-hearth Steel	B	0.07	0.41	0.042	0.042	..	0.532	2	•	•	..	..	..	..	..	..	..
S	Open-hearth Iron	B	0.02	0.02	0.006	0.022	0.004	0.022	14	4.5	4.5	4.5	4.5	4.5	5.0	5.0	5.0	5.0
D	Open-hearth Iron	A	0.02	0.03	0.004	0.022	0.002	0.024	6	5.5	9.4	9.4	10.5 A	10.5 B	11.0 C	..	..	..
X	Open-hearth Iron	B	0.02	0.06	0.007	0.031	0.004	0.027	14	4.0	5.5	5.5	7.9	8.4	8.4 A	9.0	9.0	9.0
C	Open-hearth Iron	A	0.01	0.03	0.002	0.027	0.002	0.144	2	11.0	11.0	..	..	..	..	..	..	..
C	Open-hearth Iron	A	0.02	0.03	0.006	0.036	0.003	0.195	10	8.4 A	9.9 B	10.5 C	11.0	11.0	11.0	11.0	11.0	11.0
U	Open-hearth Iron	B	0.02	0.07	0.008	0.037	0.005	0.260	14	9.9	9.9	9.9 A	10.5	10.5	10.5	10.5	10.5	11.0 B
V	Open-hearth Iron	B	0.02	0.05	0.007	0.021	0.005	0.304	14	10.5	10.5	10.5	11.0	11.0	11.0	11.0	11.0	11.0
A	Bessemer Steel	A	0.04	0.39	0.089	0.040	0.007	0.014	15	3.1	3.1	3.1	4.0	4.0	4.0	5.5	6.5	7.0 A
Z	Bessemer Steel	B	0.07	0.44	0.107	0.046	0.003	0.011	2	4.0 A	4.0 B	..	..	..	..	..	..	..
Z 1	Bessemer Steel	B	0.06	0.38	0.077	0.035	0.009	0.130	2	•	•	..	..	..	..	..	..	..
I	Bessemer Steel	A	0.04	0.37	0.097	0.068	0.008	0.252	19	•	•	•	•	•	•	•	•	•
Z 2	Bessemer Steel	B	0.06	0.37	0.094	0.038	0.007	0.263	2	•	•	.	..	..	..	..	..	..
Z 3	Bessemer Steel	B	0.05	0.37	0.114	0.048	..	0.533	2	•	•	..	..	..	..	..	..	..
Y	Wrought Iron	B	0.03	0.06	0.139	0.021	0.218	0.020	3	3.5	6.5 A	8.4 B	..	..	..	..	..	..
E	Wrought Iron	A	0.03	0.03	0.114	0.021	0.134	0.283	12	8.4	10.5	•	•	•	•	•	•	•
								Total.....	219									

Life of Each Failed Sheet, yr.[e]										Number of Sheets in Test	Number of Sheets Failed	Average Life of Sheets, yr.	Group[b]
..	.	..	..	..	..	..	..	..	..	2	2	3.8	Z 4
3.5	3.5	3.5	..	..	..	..	..	..	.	12	12	3.1	O
•	•	..	..	..	..	..	..	..	..	11	7	..	B 12[c]
•	•	•	•	•	..	..	..	..	..	14	2	..	M
..	..	..	..	..	..	..	..	..	.	2	0	..	B 9 and 11
..	..	..	..	..	..	..	..	..	..	2	0	..	Z 506[d]
												..	Z 508[d]
•	•	•	•	•	..	..	..	..	..	14	8	..	T
•	•	•	•	•	•	•	..	..	..	16	0	..	K
•	•	..	..	..	..	..	..	..	..	11	0	..	H
..	..	..	..	..	..	..	..	..	..	2	0	..	Z 6
..	..	.	..	..	..	..	..	..	..	2	0	..	Z 7
5.0	5.0	5.0	5.0	5.5	..	..	..	..	..	14	14	4.9	S
..			..	..	..	..	..	..	..	6	6	9.4	D
9.4	9.9	10.5 B	10.5	10.5	..	..	..	..	..	14	14	8.4	X
..	..	..	..	..	..	..	..	..	..	2	2	11.0	C
11.0	..	.	..	..	..	..	..	..	..	10	10	10.6	C
11.0 C	11.0	11.0	11.0	11.0	..	..	..	..	..	14	14	10.6	U
11.0	11.0	11.0	11.0	11.0	..	..	..	..	..	14	14	10.9	V
8.4 B	8.4 C	8.4	8.4	8.4	11.0	..	..	..	..	15	15	6.2	A
..	.	.	..	..	.	..	..	..	..	2	2	4.0	Z
..	..	..	..	.	..	..	..	..	..	2	0	..	Z 1
•	•	•	•	•	•	•	•	•	•	19	0	..	I
..	..	.	..	..	.	..	..	..	..	2	0	..	Z 2
..	.	..	..	..	..	..	..	..	..	2	0	..	Z 3
..		..	..	..	..	..	..	..	..	3	3	6.1	Y
•	•	•	..	..	..	..	..	..	..	12	2	..	E
								Total		219	127		

• Indicates unfailed sheets at end of test, April 16, 1928, after exposure of 11 yr.

[a] *Proceedings*, Am. Soc. Testing Mats., Vol. XXVIII, Part I, p. 152 and Plate I (1928).

[b] The suffix number after the Z sheet designations refers to first digit of the three identification numbers.

[c] Sheet analysis as given in the Analysis of Steel Sheets, Series "A," for Corrosion Tests, *Proceedings*, Am. Soc. Testing Mats., Vol. XVI, Part I, p. 157 (1916).

[d] Sheet analysis as given in the Analysis of Steel Sheets, Series "B," *Proceedings*, Am. Soc. Testing Mats., Vol. XVIII, Part I, p. 178 and Plates I and IV (1918).

[e] When a "failed" sheet was reserved, its loss of weight can be connected with the "years to failure" by comparing the letter beside "life" with the letter at the top of the loss of weight columns.

[f] Symbols used to designate perforations in specimens 12-in. square:

few	3 to 10 holes.	B	50 to 100 holes.
B—	10 to 50 holes.	B+	Over 100 holes.
		OK	Unperforated.

[g] Original weight assumed to be 1.25 lb. per sq. ft.

[h] Not received.

TABLE VI.—RECORD OF FAILURES AT PITTSBURGH OF NO. 22-GAGE COPPER-BEARING AND NONCOPPER-BEARING CORRUGATED BLACK SHEETS.

Sheets Exposed December 12, 1916. Inspections Made Semiannually from 1917 to 1923. Rearrangement of Data from 1923 Report of Committee A-5, Subcommittee III.[a]

Group	Designation	Series	Average Analysis, per cent						Number of Sheets in Test	Life of Each Failed Sheet, yr.																		Number of Sheets in Test	Number of Sheets Failed	Average Life of Sheets, yr	Group
			Carbon	Manganese	Phosphorus	Sulfur	Silicon	Copper																							
Z....	Open-hearth Steel	B	0.10	0.32	0.069	0.044	0.002	0.018	3	1.8	1.8	1.8	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	3	3	1.8	....Z
O....	Open-hearth Steel	A	0.12	0.54	0.008	0.030	0.25	0.020	12	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	..	..	..	..	..	..	12	12	1.3	....O
B....	Open-hearth Steel	A	0.09	0.38	0.017	0.062	0.04	0.082	4	1.8	2.3	2.9	3.4	..	..	..	..	..	..	..	..	..	..	..	..	..	..	4	4	2.6	....B
M...	Open-hearth Steel	B	0.09	0.42	0.013	0.041	0.01	0.185	14	3.4	3.4	3.4	3.8	3.8	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.8	..	..	..	..	14	14	4.1	...M
B....	Open-hearth Steel	A	0.06	0.27	0.014	0.053	0.006	0.179	9	2.9	3.4	3.8	3.8	4.3	4.3	4.3	4.8	4.8	..	..	..	..	..	..	..	..	..	9	9	4.0	....B
Z....	Open-hearth Steel	B	0.06	0.35	0.049	0.059		0.212	3	4.8	4.8	4.8	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	3	3	4.8	....Z
T....	Open-hearth Steel	B	0.08	0.31	0.009	0.020	0.005	0.227	14	2.9	2.9	3.4	3.4	3.4	3.4	3.4	3.8	3.8	3.8	3.8	3.8	3.8	3.8	..	..	..	..	14	14	3.5	....T
K....	Open-hearth Steel (acid)	A	0.11	0.45	0.091	0.046	0.004	0.237	16	4.8	4.8	5.3	5.3	5.8	5.8	5.8	5.8	5.8	5.8	5.8	*	*	*	*	*	..	..	16	11	..	....K
H....	Open-hearth Steel	A	0.07	0.39	0.016	0.027	0.004	0.244	12	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.8	5.3	5.8	..	..	..	..	..	..	12	12	4.6	...H
Z....	Open-hearth Steel	B	0.07	0.39	0.059	0.058	..	0.268	3	4.8	4.8	4.8	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	3	3	4.8	....Z
Z....	Open-hearth Steel	B	0.07	0.41	0.050	0.050	..	0.621	3	4.3	5.3	6.3	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	3	3	5.3	....Z
S...	Open-hearth Iron	B	0.02	0.023	0.006	0.022	0.004	0.022	14	1.3	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	..	..	..	..	14	14	1.8	....S
D....	Open-hearth Iron	A	0.02	0.026	0.004	0.022	0.002	0.024	9	1.8	1.8	1.8	2.3	2.3	2.3	2.3	2.3	2.3	..	..	..	..	..	..	..	..	..	9	9	2.1	....D
X....	Open-hearth Iron	B	0.02	0.055	0.007	0.031	0.004	0.027	14	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	..	..	..	..	14	14	1.8	X
C....	Open-hearth Iron	A	0.01	0.028	0.002	0.027	0.002	0.139	2	2.9	3.4	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	2	2	3.2	C
C....	Open-hearth Iron	A	0.02	0.028	0.006	0.036	0.003	0.190	9	2.9	2.9	2.9	2.9	3.4	3.4	3.4	3.8	4.3	..	..	..	..	..	..	..	..	..	9	9	3.3	C
U....	Open-hearth Iron	B	0.02	0.074	0.008	0.037	0.005	0.260	14	2.9	3.4	3.4	3.4	3.8	3.8	3.8	3.8	3.8	3.8	4.3	4.3	4.3	4.3	..	..	..	..	14	14	3.8	....U
V....	Open-hearth Iron	B	0.02	0.051	0.007	0.021	0.005	0.304	14	2.9	2.9	3.4	3.4	3.4	3.8	3.8	3.8	3.8	3.8	3.8	3.8	4.3	4.3	..	..	..	..	14	14	3.7	V
A.	Bessemer Steel	A	0.04	0.39	0.089	0.040	0.007	0.014	17	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.8	..	17	17	1.3	....A
Z...	Bessemer Steel	B	0.06	0.37	0.119	0.048	0.003	0.013	3	1.3	1.8	1.8	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	3	3	1.6	....Z
Z....	Bessemer Steel	B	0.07	0.40	0.088	0.048	0.009	0.133	3	4.3	5.8	5.8	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	3	3	5.3	....Z
I...	Bessemer Steel	A	0.04	0.37	0.097	0.068	0.008	0.252	18	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	18	..	..	I
Z....	Bessemer Steel	B	0.04	0.37	0.084	0.038	0.007	0.257	3	5.3	5.8	5.8	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	3	3	5.6	....Z
Z....	Bessemer Steel	B	0.04	0.37	0.100	0.045	..	0.533	2	5.8	5.8	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	2	2	5.8	....Z
Y....	Wrought Iron	B	0.03	0.055	0.139	0.021	0.22	0.020	3	2.3	2.3	2.3	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	3	3	2.3	....Y
E....	Wrought Iron	A	0.03	0.034	0.114	0.021	0.13	0.283	12	1.8	1.8	2.3	2.3	2.3	2.3	2.9	2.9	2.9	2.9	3.4	3.4	..	..	..	..	..	..	12	12	2.6	....E
								Total	230																	Total		230	207		

* Indicates unfailed sheets at end of test, March, 1923, after exposure of 6.3 yr.

[a] *Proceedings*, Am. Soc. Testing Mats., Vol. 23, Part I, p. 147 and Plate II (1923).

Pittsburgh, respectively. For the two wrought irons (copper bearing and residual copper), the similar factor was 1.1 at both Annapolis and Pittsburgh. Too few of the wrought iron sheets perforated during the 11-yr exposure at Fort Sheridan to make a comparison.

5. The Pittsburgh and Fort Sheridan locations were on the average 8.1 and 2.6 times as corrosive as Annapolis, respectively.

6. The ratios of corrosivity of the three atmospheres varied greatly when the years to failure of different steels were used as a means of comparison.

TABLE VII.—COMPARISON OF INSPECTION RESULTS OF ATMOSPHERIC EXPOSURE TESTS OF 22-GAGE UNCOATED STEEL SHEETS.

Material	Range of Copper, per cent	Groups	Average Number of Sheets	Annapolis —34.5 yr	Ft. Sheridan —11 yr		Pittsburgh—5.8 yr	
				Average Life of Failed Sheets, yr	Number Unfailed	Average Life of Failed Sheets, yr	Number Unfailed	Average Life of Failed Sheets, yr
Open-hearth Iron	0.02 to 0.03	3	35	14.1	0	7.1	0	1.9
Open-hearth Iron	0.14 to 0.30	4	39	19.6	0	10.7	0	3.6
Open-hearth Steel (Basic)	0.02	2	15	11.6	0	3.2	0	1.4
Open-hearth Steel (Basic)	0.08 to 0.27	7	58	23.3	35	11.0[a]	0	4.0
Open-hearth Steel (Basic)	0.6	1	3	30.2	3	...	0	5.3
Open-hearth Steel (Acid)	0.2	1	16	29.9	16	...	5	5.5[a]
Bessemer Steel	0.01	2	20	17.1	0	6.0	0	1.4
Bessemer Steel	0.14 to 0.27	3	24	28.3	24	...	18	5.5[a]
Bessemer Steel	0.5	1	2	33.0	2	...	0	5.8
Wrought Iron	0.02	1	3	20.3	0	6.1	0	2.3
Wrought Iron	0.28	1	12	22.3	10	9.5[a]	0	2.6

[a] Attention is called to the fact that data are incomplete.

Tests Exposed in 1926:

The test consisted of galvanized sheets having five different weights of coatings and having some steels in three sheet thicknesses, as well as an uncoated sheet from each manufacturer represented. Specimens were exposed at Altoona, Pittsburgh, and State College, Pa., Sandy Hook, N. J., and Key West, Fla. As described in a previous report (1952), the tests at Pittsburgh, Sandy Hook, and Key West have been discontinued for various reasons. However, corrosion had proceeded so far that nearly all the information that would have been obtained by continuing the tests had been secured before the sheets were discarded.

The years to the appearance of the first rust and the years until 100 per cent of the area was rusted are proportional, within the error of measurement, to the weight of coating. Considering the variations in weight of zinc coatings as made in 1925, the various points lie closer to a straight line than might be expected. It is seen in Fig. 1 that the slopes of the "100 per cent rust" lines are different from those of the "first rust." This is caused by the fact that on the heavier-coated sheets, the range in the actual thickness of zinc was greater than that on the lightly coated sheets. Perforation data for uncoated sheets are in accordance with data found in the Pittsburgh, Fort Sheridan, and Annapolis tests.

Many of the galvanized sheets exposed at Pittsburgh had not perforated when the test was discontinued. The curves shown in Fig. 1 were plotted from perforation data of three heats of open-hearth iron that in all coating weights had perforated. The uncoated 22-gage sheets at Pittsburgh were found to be perforated in two years. The time to first rust of the 0.75 oz per sq ft coated sheet was two years and the time to 100 per cent rust was about four years; yet these sheets did not become perforated until after 14 yr. This anomaly is explained by the fact that the zinc on the groundward-exposed surface does not corrode nearly so fast as the zinc on the skyward surface (only the per cent of rust on the skyward surface was recorded). It is known that in atmospheres of this type uncoated steel sheets exposed 30 deg to the horizontal corrode 50 per cent more on the groundward side than on the skyward side. However, the base metal of the galvanized sheets could not rust until the zinc had been removed from the groundward surface; therefore, the perforation time of even a lightly galvanized sheet is much longer than that of an uncoated sheet of the same composition. The slopes of the 100 per cent rust lines and of the perforation lines, Fig. 1, are practically equal. The above observations also hold for Altoona.

TABLE VIII.—RATIOS OF CORROSIVITY OF THREE TEST LOCATIONS.

Read Horizontally

Material	Corrosivity		
	Annapolis	Fort Sheridan	Pittsburgh
Open-hearth Iron (low copper)	1	2.0	7.4
Open-hearth Iron (copper)	1	1.8	5.5
Open-hearth Steel (low copper)	1	3.6	7.7
Open-hearth Steel (copper	1	2.1	5.5
Bessemer Steel (low copper)	1	3	13.1
Bessemer Steel (copper)	1	*	5.1[a]
Wrought Iron (low copper)	1	3.3	9.1
Wrought Iron (copper)	1	*	8.3
Average	1	2.6	8.1

* Insufficient data available.

[a] Only 18 of 24 sheets failed.

TABLE IX.—RATIOS OF LIVES BY CLASSES OF MATERIALS.

Read Vertically

Material	Corrosivity		
	Annapolis	Fort Sheridan	Pittsburgh
Open-hearth Iron (low copper)	1	1	1
Open-hearth Iron (copper)	1.4	1.5	1.9
Open-hearth Steel (low copper)	1	1	1
Open-hearth Steel (copper)	2.0	*	2.7
Bessemer Steel (low copper)	1	...	1
Bessemer Steel (copper)	1.7	*	4.2
Average	1.7	*	2.9
Wrought Iron (low copper)*	...	...	...
Wrought Iron (copper)*	...	...	...

* Insufficient data available.

It is evident that the compositions of the base metals in these tests had little or no effect on the corrosion rate of the zinc coating, but that after the zinc had been corroded away, the inherent resistance of the steel as determined by its composition was the major factor in the "years to perforation."

The data from the final inspection of the tests at Sandy Hook and Key West were given in the 1952 *Proceedings*[1] and are given as Tables X and XI. Three outstanding observations can be deduced from the data.

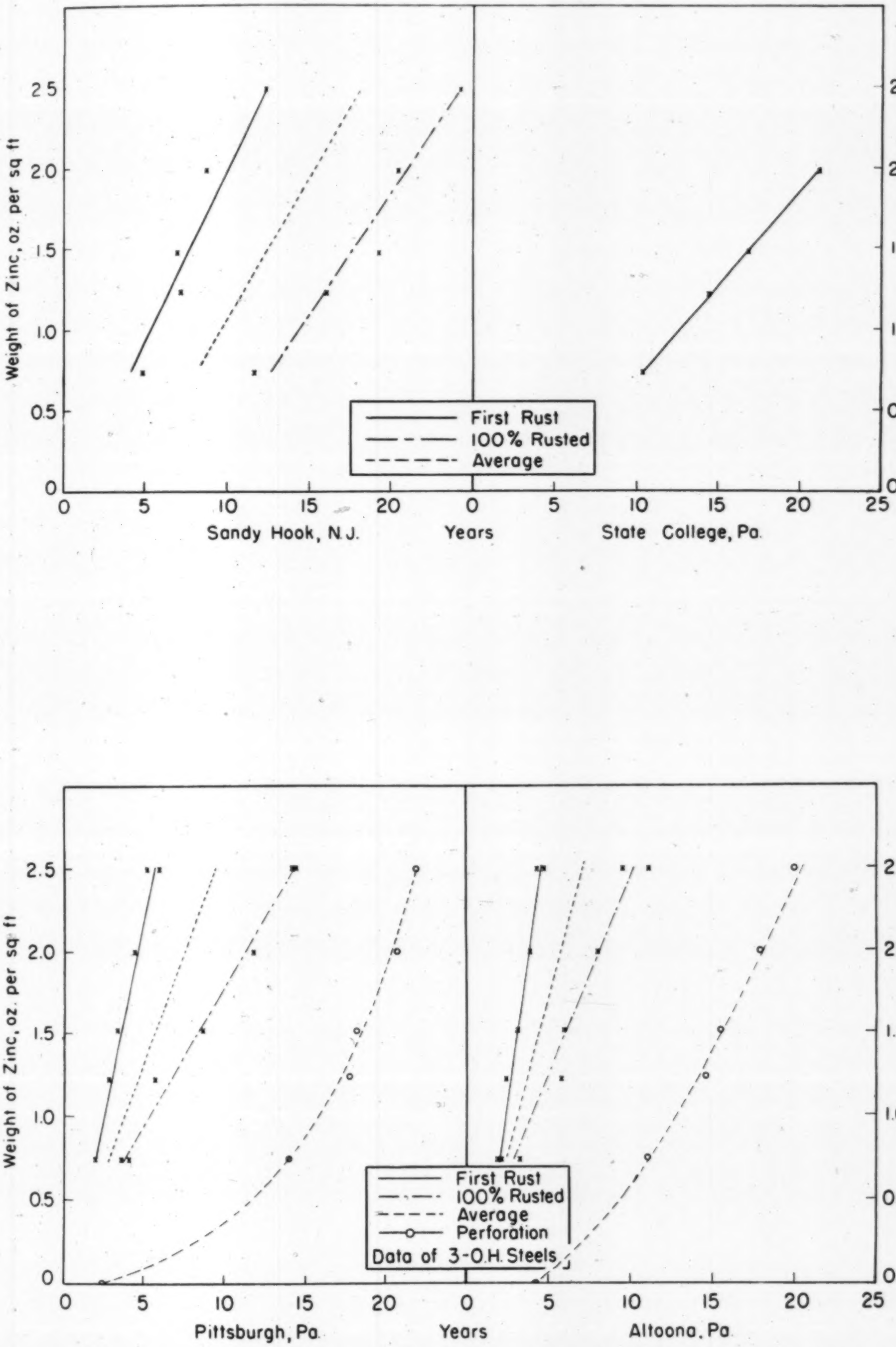

FIG. 1.—Rusting of Galvanized Steel Test Specimens.

TABLE X.—LIFE OF CORRUGATED GALVANIZED AND BLACK SHEETS, 26 BY 30 IN.
Exposed at Sandy Hook, N. J., on May 20, 1926.

Sheet	No. 16 Gage, 2.5 oz per sq ft[a]		No. 22 Gage, 2.5 oz per sq ft[a]		No. 22 Gage, 2.0 oz per sq ft[a]		No. 22 Gage, 1.5 oz per sq ft[a]		No. 22 Gage, 1.25 oz per sq ft[a]		No. 22 Gage, 0.75 oz per sq ft[a]		No. 28 Gage, 0.75 oz per sq ft[a]			No 22 Gage, Uncoated
	Years To		Years To		Years To		Years To		Years To		Years To		Years To			
	1st Rust	100 per cent Rust	1st Rust	100 per cent Rust	1st Rust	100 per cent Rust	1st Rust	100 per cent Rust	1st Rust	100 per cent Rust	1st Rust	100 per cent Rust	1st Rust	100 per cent Rust	Perforation	Years To Perforation
R (T)	13.4	25.0	12.4	•	8.4	•	6.4	17.9	7.4	14.4	....	....	....	....	....	5.9
(B)	13.4	•	12.9	•	9.4	21.9	7.4	19.4	6.9	15.9						
V (T)	12.4	24.0	10.9	24.0	9.9	19.4	7.4	19.9	6.4	19.4	5.4	13.4	....	....	....	4.9(V)
(or U) (B)	10.9	25.0 (U)	12.4	23.0	10.4	19.4	6.9	20.4	7.4	15.4	4.5	11.0				5.4(U)
N (T)	....	....	11.4	•	9.4	•	7.4	18.4	6.9	15.4	4.5	11.4	4.5	11.4	24.0	5.9
(B)			10.4	•	9.9	20.9	7.4	17.4	5.9	15.4	4.5	11.0	6.4	12.0	25.0	
T (T)	12.4	25.0	15.9	•	9.9	23.0	6.9	17.9	5.9	15.9	4.5	13.4	4.5	13.4	20.9	6.4
(B)	12.4	24.0	16.4	•	9.9	19.4	6.9	14.4	5.4	15.4	4.5	11.0	5.4	12.0	25.5	
Y (T)	10.9	•	11.4	23.0	8.4	•	7.4	17.4	6.4	16.4	4.5	11.0	4.5	12.0	....	....
(B)	12.4	•	13.4	•	8.4	24.0	8.4	17.9	6.9	13.4	5.4	13.4	4.5	11.4	....	
S (T)	10.4	•	11.9	•	9.9	21.4	7.4	15.9	5.9	12.9	4.5	9.9	4.5	9.4	20.9	9.9
(B)	11.4	•	13.4	•	12.4	23.0	9.4	16.9	7.4	15.4	4.9	9.4	5.4	9.4	25.5	
C (T)	....	....	11.4	•	8.4	25.0	7.4	19.4	6.9	15.4	4.5	12.4	....	....	....	10.4
(B)			18.4	•	9.4	24.0	7.4	19.4	7.4	14.4	4.5	11.4				
K (T)	10.9	•	11.4	•	10.4	20.9	8.4	15.9	7.4	13.9	4.5	9.4	4.5	10.0	24.0	12.4
(B)	10.4	•	12.9	•	11.4	23.0	8.4	17.4	7.4	13.9	6.4	10.4	4.9	10.0	25.0	
W (T)	....	....	13.4	•	11.4	23.0	8.4	17.4	7.4	14.4	....	....	....	....	....	4.9
(B)			14.4	•	11.4	21.9	7.4	19.4	6.4	16.4						
Average	11.8	....	13.1	....	9.9	....	7.6	17.9	6.8	15.2	4.8	11.3	4.9	11.1	....	....

• Not perforated at end of test (25 years).
[a] Coating weight is "oz per sq ft" of sheet (both sides).

1. With average years to first rust of the 0.75 oz per sq ft galvanized sheets and with perforation of three open-hearth irons as basis for comparison, the relative corrosiveness of the five locations was as follows:

	Relative Corrosiveness		
	To Zinc	To Open-Hearth Irons (R, V, and U)	To Open-Hearth Copper Steel (K)
Key West	1.0	1.0	1.0
State College	1.7	0.14	[a]
Sandy Hook	3.8	0.7	0.37
Pittsburgh	8.4	1.6	0.28
Altoona	9.2	0.8	0.35

[a] Not yet perforated.

The differences in calculated corrosiveness toward zinc, iron, and copper steel are caused partly by the protective coating that developed on the zinc in the marine atmosphere at Key West and by the comparatively early failure of the 28 by 30-in. corrugated uncoated sheets at that location. In the marine atmosphere, the attack on the groundward side near the lower edge of such specimens is very much greater than in industrial atmospheres.

Because of the long time required for uncoated, nonalloyed steel sheets to show perforations in any except the very severe locations, the subcommittee recommends that no future atmospheric corrosion testing be done by perforation methods and that consideration be given to loss of weight methods.

2. As shown above, the atmosphere at Sandy Hook was much more corrosive to zinc than the atmosphere at Key West. The prevailing westerly winds at the former location undoubtedly carry sufficient industrial contaminants to cause the corrosion of zinc to be greater than in a purely marine atmosphere.

3. The severe yet localized attack on the groundward surfaces of the galvanized sheets at Key West, which resulted in perforations in all but twelve of the eighty-four 22-gage sheets, did not occur at any other test site. The severity of this attack is emphasized by the perforation of five of the ten 16-gage 2.5-oz coated sheets. At the end of the test, January, 1952 (25.5 yr), only four sheets showed localized attack that had not resulted in visible perforations. We have no explanation for the peculiar type of attack, nor for the absence of attack on the nine sheets in the test.

It is seen in Fig. 1 that the corrosion of zinc is even less affected by minor yearly changes in corrosivity of the atmosphere at State College than at Pittsburgh, Altoona, and Sandy Hook. Also, the slope of the line is noticeably

TABLE XI.—LIFE OF CORRUGATED GALVANIZED AND BLACK SHEETS 26 BY 30 IN.
Exposed at Key West, Fla. on June 9, 1926.

Sheet	No. 16 Gage, 2.5 oz per sq ft[a]		No. 22 Gage, 2.5 oz per sq ft[a]		No. 22 Gage, 2.0 oz per sq ft[a]		No. 22 Gage, 1.5 oz per sq ft[a]		No. 22 Gage, 1.25 oz per sq ft[a]			No. 22 Gage, 0.75 oz per sq ft[a]			No. 28 Gage, 0.75 oz per sq ft[a]			No. 22 Gage, Un-coated
	Years to		Years to		Years to		Years to		Years to			Years to			Years to			
	Spots	Perforation	Spots	Perforation	Spots	Perforation	Spots	Perforation	1st Rust	Spots	Perforation	1st Rust	Spots	Perforation	1st Rust	Spots	Perforation	Years to Perforation
R (T)	24.8	•	•	•	19.8	21.5	20.8	21.5	•	14.8	17.8	....	....	....	....	....	....	
(B)	19.8	20.8	22.8	25.5	17.8	19.8	11.8	17.8	•	11.8	14.8	....	....	....	....	....	....	3.6
V (T)	19.8	21.5 (U)	19.8	21.5	17.8	20.8	19.8	21.5	•	11.8	17.8	13.8	14.8	17.8	....	....	....	3.6(U)
(or U) (B)	24.8	25.5 (U)	19.8	21.5	17.8	19.8	12.8	17.8	•	12.8	17.8	19.8	11.8	14.8	....	....	...	3.6(V)
N (T)	....	....	25.5	•	21.5	24.8	12.8	22.8	21.5	13.8	14.8	17.8	10.6	11.8	19.8	12.8	21.5	
(B)	....	....	20.8	25.5	19.8	21.5	13.8	17.8	21.5	11.8	17.8	17.8	11.8	17.8	20.8	19.8	20.8	3.6
T (T)	19.8	21.5	•	•	22.8	25.5	12.8	17.8	•	17.8	21.5	17.8	12.8	20.8	17.8	10.6	21.5	
(B)	24.8	•	•	•	17.8	17.8	13.8	17.8	•	11.8	17.8	17.8	10.6	14.8	17.8	12.8	17.8	3.6
Y (T)	25.5	....	20.8	....	....	....	19.8	....	•	10.6	....	21.5	11.8	....	19.8	11.8	....	
(B)	17.8	....	24.8	....	11.8	....	11.8	....	•	10.6	....	21.5	10.6	...	19.8	13.8	....	....
S (T)	•	•	24.8	•	24.8	25.5	11.8	21.5	•	12.8	17.8	19.8	11.8	14.8	17.8	11.8	14.8	
(B)	17.8	19.8	22.8	25.5	17.8	21.5	13.8	17.8	•	13.8	17.8	19.8	10.6	14.8	17.8	10.6	11.8	3.6
C (T)	....	....	•	•	•	•	17.8	17.8	•	12.8	14.8	19.8	12.8	25.5	....	....	....	5.7
(B)	....	....	22.8	25.5	20.8	21.5	12.8	17.8	•	13.8	17.8	13.8	11.8	14.8	....	....	....	
K (T)	•	•	•	•	20.8	•	12.8	19.8	•	17.8	20.8	17.8	22.8	22.8	17.8	14.8	21.5	
(B)	•	•	20.8	25.5	19.8	24.8	17.8	21.5	•	14.8	17.8	17.8	10.6	19.8	17.8	11.8	21.5	4.6
W (T)	....	....	•	•	22.8	•	13.8	24.8	•	•	25.5	....	....	....	....	....	....	
(B)	....	....	25.5	•	22.8	25.5	19.8	21.5	•	19.8	22.8	....	....	....	....	....	....	3.6

[a] Coating weight is "oz per sq ft" of sheet (both sides).

• Had not failed at end of test January, 1952 (25.5 yr)

1st Rust is based on same standards as at other test locations and ignores spots originating from below.

Spots—First sign on top surface of corrosion originating from underside of sheet. These yellow spots blister and crack and finally become "perforations."

less than those in the plots for the other three locations.

CONCLUSIONS

Uncoated Steels:

In the opinion of the subcommittee, the exposure tests discussed above show that:

1. In all five atmospheres, steels or irons having 0.2 per cent minimum copper content have better resistance than steels with residual copper contents. The ratios vary from about 1 to 1 to 4 to 1 depending upon the type of material and the location. The average life of all sheets with 0.2 per cent minimum copper is about *twice* that of sheets with residual copper.

2. The corrosiveness of the several atmospheres varies more than the differences in corrosion resistance of the materials tested. The greatest ratio found of the average life of the most resistant steels to the average life of the least resistant is about 4 to 1; whereas, the greatest ratio found for the corrosiveness of Pittsburgh to that of Annapolis is 12 to 1, and for Pittsburgh to State College is 11 to 1.

Galvanized Sheets:

3. The corrosion rate of the zinc on galvanized sheets is practically linear in industrial or rural atmospheres. This is also the case in a marine atmosphere that is polluted with industrial contaminants. In other words, in these atmospheres a sheet with double the weight of coating of another can be expected to last twice as long before rusting of the base metal occurs.

4. The composition of the base metals had no measurable effect on the life of the zinc coatings; however, the composition of the base metals was the major factor in the "years to perforation."

5. The corrosion rate of zinc varies more with the type (marine, industrial) of atmosphere than does that of steel or iron. Galvanized sheets remained unrusted nine times as long at Key West as at Pittsburgh.

This report has been submitted to letter ballot of Subcommittee XIV and unanimously approved.

Respectfully submitted on behalf of the subcommittee,

C. P. LARRABEE,
Chairman.

REPORT OF SUBCOMMITTEE XV ON ATMOSPHERIC EXPOSURE TESTS OF WIRE AND WIRE PRODUCTS

(COVERING 1953 INSPECTIONS)

This report summarizes the results of the atmospheric corrosion tests on wire and wire products through 1953. Detailed results are reported in the odd-numbered years, and reference to these earlier reports of Committee A-5 on Corrosion of Iron and Steel, which appeared in the Society's *Proceedings* for 1939, 1941, 1943, 1945, 1947, 1949, 1951, and 1953 will be helpful in studies of these data. These earlier reports contain descriptions of the test methods, micrographs, and other characterizations of specimens in the test as well as the data assembled during previous inspections.

Most of the materials being tested are bare and zinc-coated steel wires and wire products, but copper-covered and lead-coated steel wires and chromium and chromium-nickel steel wires are also included. The coatings are expressed in weight terms of ounces per square foot of surface. For ready comparisons of coating thickness, 1 oz per sq ft of surface may be considered as averaging 0.0017 in. thick for zinc coatings, 0.0013 in. thick for copper coatings, and 0.0010 in. thick for lead coatings.[1]

Specimens of wires and wire products have been exposed for approximately 17 yr at eleven locations. The location of these sites and their general classification regarding atmospheres are as follows:

Test Location	General Type of Atmosphere	Remarks
Pittsburgh, Pa.	Severe industrial	On Brunot Island in the Ohio River about 2 miles west of the city
Bridgeport, Conn.	Industrial	In the city
Sandy Hook, N. J.	Seacoast	About 300 yards from the Atlantic Ocean
Santa Cruz, Calif.	Rural (marine)	About 3 miles from the Pacific Ocean
State College, Pa.	Rural	Central Pennsylvania
Lafayette, Ind.	Rural	Wabash River Valley
Ames, Iowa	Rural	Central Iowa
Manhattan, Kans.	Rural	Kansas River Valley
Ithaca, N. Y.	Rural	Central New York
College Station, Texas	Rural	About 120 miles inland
Davis, Calif.	Rural	About 80 miles inland

At each location more than 900 specimens were exposed. These included short lengths of wire (42 in. long) and wire strand at all locations, farm field fence at nine sites, barbed wire at eight locations, and chain link fence at eight locations.

The extent of corrosion is being meas-

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[1] The lead-coated wires in these tests were lead coated over a bonding coat of zinc. See *Proceedings*, Am. Soc. Testing Mats., Vol. 43, p. 87 (1943) for analysis of lead coatings.

TABLE A.—REPORT OF GROUP AVERAGES THROUGH 1953—17-YR EXPOSURE.

Abbreviations and symbols used to designate appearance or state of corrosion: M = metallic; G = gray; MG = intermediate between M and G; Y = yellowed, or rust stained, but not showing actual rough rust of base metal; R = rust of base metal; PHR, PHY = rust or yellowed in pinholes; SR, SY = speckled appearance of rust or yellowing; Br, Gn, respectively, signify corroded to brown or green appearance; D = dark (dirt or soot) to the exclusion of a better observation; GY = predominantly gray but showing indication of Y. Figures preceding R (as 5, 10, 50, 100) are percentages. Italicized readings are for those groups which as a group have not reached 1R or 100R.

Coating Group or Weight of Zinc, oz per sq ft of surface	Number in Group	Pittsburgh, Pa. (14 yr)		Sandy Hook, N. J. (15 yr)		Bridgeport, Conn.		State College, Pa.		Lafayette, Ind.		Ithaca, N. Y.		Ames, Iowa		College Station, Tex.		Manhattan, Kans.		Santa Cruz, Calif.		Davis, Calif.	
		Average of Observed Years of Exposure until 1R to 100R or State of Corrosion after Approximately 17-yr Exposure																					
		1R	100R	1R	100R	1R	100R	1R	100R	1R	100R	1R	100R	1R	100R	1R	100R	1R	100R	1R	100R	1R	100R
											UNFABRICATED WIRES*												
0.20 to 0.30	6	0.8	1.3	1.7	2.8	2.1	2.8	5.1	6.2	4.6	5.6	5.6	6.2	6.3	7.5	8.5	12.8	10.4	*59R*	12.6	*91R*	12.3	*47R*
0.25 to 0.35	8	0.9	1.4	2.5	3.2	2.3	3.5	4.9	6.7	4.8	6.3	5.6	7.3	6.9	9.3	9.0	*74R*	10.3	*46R*	12.3	*53R*		*34R*
0.35 to 0.45	7	1.5	2.0	2.8	3.7	2.9	3.7	6.6	8.4	5.5	6.8	6.7	8.3	8.4	11.4	11.5	*33R*		*3R*		*11R*		*GY*
0.45 to 0.55	10	1.8	2.5	3.8	5.2	3.8	5.6	7.9	10.3	7.1	9.2	8.3	10.4	10.7	*98R*		*5R*		*GY*		*GY*		*G*
0.50 to 0.60	5	1.7	2.1	4.7	6.0	4.7	5.7	9.5	11.7	8.5	10.0	9.3	11.2	12.1	*96R*		*1R*		*G*		*G*		*G*
0.60 to 0.70	12	2.2	2.8	5.6	6.8	5.4	7.1	10.2	13.2	8.8	11.4	10.4	13.0		*33R*		*2R*		*GY*		*GY*		*G*
0.70 to 0.85	10	2.1	2.8	5.9	7.2	5.7	7.1	11.3	16.3	9.8	11.9	11.1	13.3		*35R*		*1R*		*MG*		*G*		*G*
0.80 to 1.00	11	2.7	3.3	7.1	8.7	6.8	8.9		*80R*		*92R*		*88R*		*5R*		*G*		*MG*		*G*		*G*
1.20 to 1.35	2	3.7	5.0	9.4	11.5	9.0	11.5		*Y*		*53R*		*37R*		*3R*		*G*		*MG*		...		...
1.60 to 1.80	11	4.2	5.6		*10R*		*94R*		*G*		*1R*		*1.0R*		*G*		*G*		*MG*		*MG*		*MG*
2.70 to 3.00	3	7.3	8.4		*G*		*G*		*G*		*G*		*G*		*G*		*G*		*MG*		*MG*		*MG*
Cu Coat	2		*D*		*Gn*		*Gn*		*Gn*		*Gn*		*Gn*		*Br*		*Br*		*Br*		*Br*		*Br*
Pb Coat	4		*D*		*100R+Y*		*GY*		*100R+Y*		*41PHR*		*19R*		*42R*		*5R*		*8R*		*37SR*		*31SR*
12-14% Cr	6		*D*		*YSR*		*GY*		*M*		*M*		*SY*		*SY*		*4R+Y*		*M*		*65SR*		*38SR*
18% Cr-8% Ni	3		*D*		*MG*		*G*		*M*		*M*		*M*		*SY*		*MG*		*M*		*MG*		*MG*

Wire Strand

0.69 to 0.93	4	4.0 6.8	9.4 *60R*	9.9 15.3	*GY*	15.0 *13R*	*2R*	*G*	*G*	*MG*	*G*	*G*
1.03 to 1.17	3	4.9 7.0	11.9 *40R*	*45R*	*GY*	*6R*	*GY*	*G*	*G*	*MG*	*MG*	*MG*
1.32 to 1.51	4	6.0 10.0	14.1 *10R*	*32R*	*GY*	*3R*	*GY*	*G*	*G*	*MG*	*G*	*MG*
1.71 to 2.47	1	8.5 *40R*^{e}	*G*	*G*	*G*	*G*	*G*	*G*	*G*	*MG*	*MG*	*MG*
Pb Coat	1	5.0^d *D*	*100R+Y*	*10R*	*100R+Y*	*35PHR*	*17R*	*67R*	*10PHR*	*5R*	*68SR*	*10R*

Chain Link Fence

0.29 to 0.52^a	3	1.5 2.2	2.2 4.5	2.9 4.8	6.4 9.1	5.7 9.0	5.9 11.5	No Specimens Exposed	No Specimens Exposed	No Specimens Exposed	12.7 *28R*	12.8 *22R*
1.13 to 1.22^a	2	3.7 4.7	8.4 10.6	8.9 12.0	14.5 *11R*	14.0 *60R*	*11R*				*MG*	*MG*
2.09 to 2.92^a	2	6.5 7.8	*G*	*G*	*G*	*G*	*G*				*MG*	*MG*
1.40 to 1.97^b	10	3.7 6.4	9.0 12.3	9.9 13.0	*GY*	15.5 *18R*	*7R*				*MG*	*MG*
4.21^b	1	7.6 *50R*^{e}	*GY*	*GY*	*GY*	*G*	*GY*				*MG*	*MG*
Cu Coat	1	*Gn*^{c}	*Gn*	*Gn*	*Gn*	*Gn*	*Gn*				*Br*	*Br*
Pb Coat	1	5.0^d *35R*^{e}	*100R+Y*	*Y*	*5R*	*20PHR*	*20R*				*35SR*	*35SR*
18% Cr–8% Ni	1	*D*^{e}	*G*	*MG*	*M*	*M*	*M*				*MG*	*MG*

[a] Coated before weaving.
[b] Coated after weaving.
[c] Sample lost after 3-yr exposure.
[d] Pinhole rusting previously.
[e] Test discontinued after 10-yr exposure.

* Farm field fence and barbed wire made from these same wire lots corrode at about the same rate as the unfabricated wire except that in the case of farm field fence the bottom part of the fence corrodes less than the upper part; in the case of barbed wire the barbs show rust a year or two before rust appears on the main wire.

TABLE B.—REPORT OF GROUP AVERAGES THROUGH 1953—17 YEARS OF EXPOSURE.

Abbreviations and symbols used to designate appearance or state of corrosion: M = metallic; G = gray; MG = intermediate between M and G; Y = yellowed or rust stained but not showing actual rough rust of base metal; R = rust of base metal, figures preceding R (as 5, 10, 50, 100) are percentages; PHR, PHY = rust or yellowed in pinholes; SR, SY = speckled appearance of rust or yellowing; Br, Gn = corroded to a brown or green appearance; D = dark (dirt or soot) to the exclusion of a better observation; GY = predominantly gray but showing indications of Y.

Coating Group or Weight of Zinc, oz per sq ft of surface	Number in Group	State College, Pa. (15.4 yr.)	Lafayette, Ind.	Ames, Iowa	Manhattan, Kans.	Ithaca, N. Y.	Santa Cruz, Calif.	College Station, Tex.	Davis, Calif.
				FARM FIELD FENCE[a]					
0.20 to 0.30	6	100R	100R	100R	67R	100R	79R	100R	77R
0.25 to 0.35	5	100R	100R	100R	33R	100R	53R	75R	50R
0.35 to 0.45	6	100R	100R	100R	12R	100R	30R	50R	8R
0.45 to 0.55	6	100R	100R	100R	1R	100R	24R	10R	GY
0.50 to 0.60	7	99R	100R	54R	G	100R	8R	4R	G
0.60 to 0.70	8	96R	96R	46R	G	91R	10R	3R	MG
0.70 to 0.85	8	70R	94R	12R	MG	79R	G	G	MG
0.80 to 1.00	8	30R	74R	3R	MG	53R	3R	1R	MG
1.60 to 1.80	3	GY	2R	G	MG	MG	MG	G	MG
2.70 to 3.00	2	M	G	G	MG	MG	MG	G	MG
12–14% Cr, cold drawn	1	M	M	SY	M	MG	85SR	20R	80R
12–14% Cr, air quenched	1	M	M	SY	MG	MG	40SR	78R	40SR
18 Cr–8 Ni	1	M	M	M	M	M	MG	M	MG
Copper covered (7.42 oz per sq ft)	1	Gn	Gn	Br	Br	Gn	Gn	Br	Br
Lead coated (1.48 oz per sq ft)	1	PHR	20PHR	30R	15R	35R	45SR	20R	75R
				BARBED WIRE					
0.20 to 0.30	3	100R	100R	100R	47R	100R	69R	73R	58R
0.35 to 0.45	3	100R	100R	100R	15R	100R	19R	13R	GY
0.50 to 0.60	3	100R	100R	41R	G	92R	13R	8R	GY
0.70 to 0.85	3	80R	100R	10R	MG	85R	G	G	MG
0.80 to 1.00	2	10R	27R	G	MG	4R	G	G	MG
1.60 to 1.80	3	GY	13R	G	MG	7R	G	G	MG
2.00 or more	3	G	G	G	MG	15R	G	G	MG
Copper covered (3.97 oz per sq ft)	2	Gn	Gn	Br	Br	Gn	GnRB	Br	BrRB
Lead coated (1.83 oz per sq ft)	2	...	40PHR	25R	10PHY	35R	33SR	4R	25SR

[a] Ratings based on upper half of fence

ured by visual examination of all specimens at the test site and by tension tests on the unfabricated wire specimens. During 1953 the Bridgeport and State College specimens were inspected in the spring by a traveling committee. Inspections were made in the fall of 1953 at the other test sites by the university people in charge of the test plots.

The summarized inspection records of corrosion through 1953 are shown in Table A for unfabricated wire specimens, wire strand and chain link fence, and Table B for farm field fence and barbed wire.

Tensile strength tests were made on 43 selected specimens from Bridgeport during 1953. These tensile strength data do not show any noticeable change from the rate of loss of tensile strength previously reported. The results of these tension tests will be given in the 1955 report.

Respectfully submitted on behalf of the Wire Test Inspection Committee,

FRED M. REINHART,
Chairman

REPORT OF COMMITTEE A-6

ON

MAGNETIC PROPERTIES*

Committee A-6 on Magnetic Properties held two meetings during the year: on June 29, 1953, during the Annual Meeting of the Society in Atlantic City, N. J., and on February 17, 1954, in East Pittsburgh, Pa., as guests of the Westinghouse Electric Corp.

There has been activity during the year in the task groups concerned with specifications for electrical sheet and strips, and normal variability of magnetic properties of electrical sheet, as well as the task groups considering the preparation of a manual of magnetic testing, and the complete revision of the specifications for a-c testing.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, A. C. Beiler.
Vice-Chairman, D. C. Dieterly.
Secretary, Milan Getting, Jr.

NEW TENTATIVE

The committee recommends the following two specifications for publication as tentative as appended hereto:[1]

Tentative Specifications for:

Flat-Rolled Grain-Oriented Electrical Steel, 3 per cent Silicon Content, in Cut Lengths or Coils.

Flat-Rolled Electrical Steel, 3.5 to 5 per cent Siicon Content, in Cut Lengths or Coils.

TENTATIVE REVISION

The committee recommends tentative revisions of the Standard General Specifications for Flat-Rolled Electrical Steel (**A 345 - 49**),[2] as appended hereto.[3]

ADOPTION OF TENTATIVE REVISIONS AS STANDARD

The committee recommends that the tentative revisions of the Standard Methods of Test for Alternating Current Core Loss and Permeability of Magnetic Materials (**A 343 - 49**),[2] issued September 5, 1952, be approved for reference to letter ballot of the Society for adoption as standard.

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[4]

This report has been submitted to letter ballot of the committee, which consists of 32 members; 20 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

R. L. SANFORD,
Chairman.

M. GETTING, JR.
Secretary.

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13–18, 1954.

[1] The new tentatives were accepted by the Society and appear in the 1954 Supplement to Book of ASTM Standards, Part 1.

[2] 1952 Book of ASTM Standards, Part 1.

[3] The revised tentative was accepted by the Society and appears in the 1954 Supplement to Book of ASTM Standards, Part 1.

[4] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

REPORT OF COMMITTEE A-7

ON

MALLEABLE-IRON CASTINGS*

Committee A-7 on Malleable-Iron Castings held two meetings during the past year: at Atlantic City, N. J., on June 30, 1953, and at Washington, D. C., on February 4, 1954.

During the year the committee lost by death the services of one of its long-time and helpful members—Mr. R. W. Parsons, who very effectively represented the Ohio Brass Co. The committee regrets the loss of Mr. Parsons but welcomes his successor, Mr. Alton W. Bardeen, Technical Director of the Company.

Prof. Peter E. Kyle of Cornell University found it necessary to resign from Committee A-7 due to pressure of other activities. The committee notes with regret the loss of his assistance.

At the present time the committee consists of 53 members, of whom 26 are classified as producers, 16 as consumers, and 11 as general interest members.

Adoption of Tentative as Standard

The committee recommends that the Tentative Specification for Malleable Iron Flanges, Pipe Fittings, and Valve Parts for Railroad, Marine and Other Heavy Duty Service (A 338 – 51 T)[1] be approved for reference to letter ballot of the Society for adoption as standard without change.

Activities of Subcommittees

Subcommittee I on Chemical and Physical Methods of Testing (L. G. Toye, chairman) has continued to give consideration to the impact testing of various types of malleable iron, giving thought to temperature effects and the determination of transition temperature values.

This report has been submitted to letter ballot of the committee, which consists of 56 members; 36 members returned their ballots, of whom 34 voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

W. A. Kennedy,
Chairman.

James H. Lansing,
Secretary.

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13–18, 1954.

[1] 1952 Book of ASTM Standards, Part 1.

REPORT OF COMMITTEE A-10

ON

IRON-CHROMIUM, IRON-CHROMIUM-NICKEL, AND RELATED ALLOYS*

Committee A-10 on Iron-Chromium, Iron-Chromium-Nickel, and Related Alloys held meetings at Atlantic City, N. J., on July 1, 1953, during the Annual Meeting of the Society, and on February 4, 1954, at Washington, D. C., during ASTM Committee Week.

The present committee consists of 105 members, of whom 45 are classified as producers, 42 as consumers, and 18 as general interest members.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, Jerome Strauss.
Vice-Chairman, L. L. Wyman.
Secretary, M. A. Cordovi.

NEW TENTATIVE

The committee recommends that the proposed Tentative Recommended Practice for Descaling and Cleaning Stainless Steel Surfaces be accepted for publication as tentative, as appended hereto.[1]

ADOPTION OF TENTATIVE AS STANDARD

The committee recommends that the Tentative Specifications for Hot-Rolled and Cold-Finished Corrosion-Resisting Steel Bars (**A 276 - 49 T**)[2] be approved for reference to letter ballot of the Society for adoption as standard with the following changes:

Section 2.—Revise to read as follows:

2. Orders for material under these specifications shall include the following information:

(*1*) Name of material: Corrosion-resisting (stainless steel) bars,
(*2*) Condition (Section 3 (*a*)),
(*3*) Finish (Section 3 (*b*) and (*c*)),
(*4*) Form,
(*5*) Applicable dimensions:
  Size,
  Thickness,
  Width, and
  Length
(*6*) Type designation (Table I),
(*7*) ASTM Designation and year of issue, and
(*8*) Special requirements (if required).

NOTE.—A typical ordering description follows: "Corrosion-resisting (stainless steel) annealed flat bar, cold-finished, 0.375 by 1 by 96 in., type 302, conforming to ASTM Standard Specifications A 276 - 54 T, except that the minimum tensile strength shall be 60,000 psi."

Section 3.—Change heading to "Condition and Finish" and revise the text to read as follows:

3. (*a*) Bars may be furnished in one of the following conditions:

Condition	
A.......	Annealed (all grades)
B........	Cold worked - high tensile (types 302, 303, 304, and 316)
T........	Tempered (types 410 and 416)
H.......	Heat-treated (types 410 and 416)

(*b*) Bars in the hot-finished condition, which conform to the tolerances shown in Tables III, IV, and V, may be furnished with one of the following finishes:

(*1*) Scale not removed (conditions *A*, *T*, *H* only),

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13–18, 1954.

[1] The new tentative was accepted by the Society and appears in the 1954 Supplement to Book of ASTM Standards, Part 1.

[2] 1952 Book of ASTM Standards, Part 1.

TABLE I.—PHYSICAL TEST REQUIREMENTS.

Type Numbers	Condition	Finish	Diameter or Thickness, in.	Ultimate Tensile Strength, min, psi	Yield Strength[a] (0.2 per cent offset), min, psi	Elongation 2 in.,[b] min, per cent	Reduction of Area, min, per cent	Brinell Hardness, max
CHROMIUM-NICKEL GRADES								
302, 303, 304, 316, 321, 347, 304L, 316L, 309, 309S, 310, and 310S	annealed	hot-finished	all	75 000	30 000[c]	40	50	...
	annealed	cold-finished	Up to ½, incl	90 000	45 000	35	45	...
			Over ½	75 000	30 000[c]	40	50	...
302, 303,[d] 304	cold worked	cold-finished	Up to ¾, incl	125 000	100 000	12	35	...
			Over ¾ to 1	115 000	80 000	15	35	...
316	high-tensile		Over 1 to 1¼	105 000	65 000	20	35	...
			Over 1¼ to 1½	100 000	50 000	28	45	...
			Over 1½ to 1¾	95 000	45 000	28	45	...
CHROMIUM GRADES								
410, 416, 430, 430F	annealed	hot-finished	all	70 000	40 000	22	50	223
	annealed	cold-finished	all	70 000	40 000	16	45	235
410, 416	tempered	hot-finished	all	100 000	80 000	15	45	262
	tempered	cold-finished	all	100 000	80 000	12	40	262
410, 416	heat-treated	hot-finished	all	120 000	90 000	12	40	321
	heat-treated	cold-finished	all rounds only	120 000	90 000	12	40	321
420	annealed	hot-finished	all	...	...	...	...	223[e]
	annealed	cold-finished	all	...	...	...	...	235[e]
440A, B, and C, 440F	annealed	hot-finished	all	...	...	...	...	269[e]
	annealed	cold-finished	all	...	...	...	...	285[e]

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[a] Yield strength shall be determined by the 0.2 per cent offset method in accordance with the Tentative Methods of Tension Testing of Metallic Materials (ASTM Designation: E 8), 1954 Supplement to Book of ASTM Standards, Part 1. An alternate method of determining yield strength may be used, based on a total extension under load of 0.5 per cent.

[b] For some specific products, it may not be practicable to use a 2-in. gage length. In the case of rounds, a gage length equal to four times the diameter may be used whenever the 2-in. gage length is not practicable. For other products, use of the specimens described in Methods E 8 is recommended.

[c] Type 304L—0.2 per cent yield strength, 25,000 psi, min. [d] Selenium-bearing analysis only.

[e] Types No. 420 and No. 440 shall be used only in the fully heat-treated condition. After hardening at 1900 F and oil-quenching, they may have a minimum Rockwell hardness as follows:

Type	Rockwell Hardness, min	Type	Rockwell Hardness, min
420	C50	440C	C59
440A	C54	440F	C59
440B	C56		

(*2*) Pickled (conditions *A*, *T*, *H* only), and

(*3*) Turned (conditions *A*, *T*, *H* only, round bars only).

(*c*) Bars in the cold-finished condition, which conform to the tolerances shown in Tables VI, VII, and VIII, may be furnished with one of the following finishes:

(*1*) Cold-drawn or cold-rolled (conditions *A*, *B*, *T* only),

(*2*) Centerless ground (all conditions, round bars only), and

(*3*) Polished (all conditions, round bars only).

Table II.—Delete the present Table II and replace by the accompanying Table I.

TABLE II.—PERMISSIBLE VARIATIONS IN SIZE OF COLD-FINISHED HEXAGONS AND OCTAGONS.

Specified Dimensions Between Opposite Sides, in.	Permissible Variations Under Specified Dimension, in.[a]
Over ½ to 1, incl.	0.004
Over 1 to 2, incl.	0.006
Over 2 to 3, incl.	0.008
Over 3	0.010

[a] No permissible variations over the specified dimension.

When it is necessary to heat treat or heat treat and pickle after cold finishing, because of special hardness or mechanical property requirements, tolerances are commonly double those shown in the table.

Tables VII and VIII.—Revise to conform with the tolerances shown in Tables 61 and 62 of Section 24 of the American Iron and Steel Institute's *Steel Product Manual.* See the accompanying Tables II and III.

REVISION OF STANDARDS, IMMEDIATE ADOPTION

The committee recommends for immediate adoption revision of the following standards, and accordingly asks for a nine-tenths affirmative vote at the Annual Meeting in order that these recommendations may be referred to letter ballot of the Society.

Standard Specifications for Corrosion-Resisting Chromium-Nickel Steel Plate, Sheet, and Strip (**A 167 - 44**).[2]

Table II.—Change the title to read "Mechanical Test Requirements."

Section 7.—Change the heading to read "Mechanical Properties." In Paragraph (*a*) change "physical properties" to read "mechanical properties." Delete "however" in the last sentence of Paragraph (*b*).

TABLE III.—PERMISSIBLE VARIATIONS IN SIZE OF COLD-FINISHED FLATS.

Specified Width or Thickness, in.	Permissible Variations from Specified Width, Over or Under, in.[a]		Permissible Variation from Thickness, Over or Under, in.[a]
	For Thicknesses ¼ in. and Under	For Thicknesses Over ¼ in.	
Over ⅜ to 1, incl.	0.004	0.002	0.002
Over 1 to 2, incl.	0.006	0.003	0.003
Over 2 to 3, incl.	0.008	0.004	0.004
Over 3 to 4½, incl.	0.010	0.005	0.005

[a] When it is necessary to heat treat or heat treat and pickle after cold finishing, because of special hardness or mechanical property requirements, tolerances are commonly double those shown in the table.

Section 8 (*b*).—Revise to read as follows:

> (*b*) Material up to and including ⅜ in. in thickness shall be bent over a single piece of flat stock of the same thickness as the material tested, allowing the test material to form its natural curvature.
>
> NOTE.—Bend may be made over a diameter equal to the thickness of the test material.

Section 8 (*c*).—Revise to read as follows:

> (*c*) Material over ⅜ in. in thickness shall be bent over two pieces of flat stock, each being of the same thickness as the material tested, allowing the test material to form its natural curvature.

NOTE.—Bend may be made over a diameter equal to two times the thickness of the test material, or over a single piece of flat stock twice the thickness of the test material.

Section 9 (a).—Revise to read as follows:

9. (*a*) Tension test specimens shall be taken from finished material and shall be selected either in the longitudinal or transverse direction. The tension test specimens shall conform to Sections 6, 7, or 8 of ASTM Method E 8. See Section 9 of Method E 8 for selection of test specimen. When the plate-type specimen is used it shall conform to the dimensions of Fig. 5 of Methods E 8 except, if desired, it may have straight parallel edges with the following dimensions: plate thickness by 1½ in. (+ ⅛ in., − ¼ in.) by 16 in. minimum length.

Figure 1.—Delete.

Figure 2.—Delete.

Section 9 (b).—Revise to read as follows:

(*b*) Transverse bend test specimens from sheet and strip shall be the full thickness of the material and approximately 1 in. in width. The edges of the test specimens may be rounded to a radius equal to one half the thickness.

Section 9 (c).—Insert a new Paragraph (*c*) as follows and reletter present Paragraph (*c*) and subsequent paragraphs accordingly:

(*c*) The width of strip for which bend tests can be made is subject to practical limitations on the length of the bend test specimen. For narrow strip the following widths can be tested:

Strip Thickness, in.	Minimum Strip Width and Minimum Specimen Length for Transverse Bend Tests, in.
0.100 and under	½
0.101 to 0.140	1
0.140 and over	1½

Bend test specimens for sheet and strip may be of any suitable length over the above minimum length.

Section 9 (f).—Revise to read as follows:

(*f*) Hardness tests may be made on the grip ends of the tension test specimens before they are subjected to the tension test.

Section 10.—Revise to read as follows:

10. In the case of sheet or strip produced in coil form, two or more tension tests (one from each end of the coil), one bend test, and one or more hardness tests shall be made on samples taken from each coil. When material is produced in sheet, strip, or plate form, one tension, one bend, and one or more hardness tests shall be made on each 100 or less sheets, strips, or plates of the same gage and heat produced under the same processing conditions.

Standard Specifications for Corrosion-Resisting Chromium Steel Plate, Sheet, and Strip (**A 176 – 49**).[2]

Table II.—Change the title to read "Mechanical Test Requirements."

Section 7.—Change the heading to read "Mechanical Properties." In Paragraph (*a*) change "physical properties" to read "mechanical properties." Add new Paragraph (*c*) to read as does Section 7 (*c*) of Specifications A 167.[2]

Section 8 (b).—Revise to read as indicated above for Section 8 (*b*) of Specifications A 167.

Section 8 (c).—Revise to read as indicated above for Section 8 (*c*) of Specifications A 167.

Section 9 (a).—Revise to read as indicated above for Section 9 (*a*) of Specifications A 167.

Figure 1.—Delete.

Figure 2.—Delete.

Section 9 (b).—Revise to read as indicated above for Section 9 (*b*) of Specifications A 167.

Section 9 (c).—Insert new Paragraph (*c*) as indicated above for Section 9 (*c*) of Specifications A 167. Reletter present Paragraph (*c*) and subsequent paragraphs accordingly.

Section 9 (f).—Revise to read as indicated above for Section 9 (*f*) of Specifications A 167.

Section 10.—Revise to read as indicated above for Section 10 of Specifications A 167.

Standard Specifications for High-Strength Corrosion-Resisting Chromium-Nickel Steel Sheet and Strip (**A 177 – 44**).[2]

Section 8 (b).—In the last sentence, delete "however."

Section 9 (c).—Revise to read as follows:

> 9. (*c*) For the 180-deg bend test in Table II [the accompanying Table IV], N is the number of pieces of flat stock, of the same thickness as the test material, over which the test material shall be bent. For the 90-deg bend tests, the inside radius of the bend shall be N times the thickness of the test material.
>
> NOTE.—The 180-deg bend test may be over a diameter equal to N times the thickness of the test material.

TABLE IV.—BEND TEST REQUIREMENTS.

Temper	0.030 in. and less in Thickness		0.031 to 0.050 in. in Thickness		0.051 in. and over in Thickness	
	Angle, deg	N[a]	Angle, deg	N[a]	Angle, deg	N[a]
Quarter hard...	180	2	180	2	90	2
Half hard......	180	4	180	8	90	2
Three-quarter hard.........	180	8	90	2½	..	..
Full hard.......	180	12	90	3½	..	..

[a] See Section 9(*c*).

Section 10 (a).—Change the first sentence to read as follows:

> (*a*) Tension test specimens shall be taken from finished material and shall be selected in the transverse direction, except in the case of strip under 9 in. wide, which shall be sampled in the longitudinal direction.

Section 10 (b).—Revise to read as follows:

> (*b*) Transverse bend test specimens from sheet and strip shall be the full thickness of the material and 1 in. in width. For strip up to 1 in. wide, longitudinal bend test specimens shall be the full thickness of the material and of the same width as the strip. For sheet or strip 1 in. wide and over, longitudinal bend test specimens shall be the full thickness of the material and approximately 1 in. in width.

Section 10.—Insert new Paragraph (*c*) to read as follows:

> (*c*) The width of strip for which transverse bend tests can be made is subject to practical limitations in the length of the bend test specimen. For narrow strip, the following widths can be tested:

Strip Thickness, in.	Minimum Strip Width and Minimum Specimen Length for Tranverse Bend Tests, in.
0.100 and under..........	½
0.101 to 0.140...........	1
0.140 and over...........	1½

> Longitudinal or transverse bend test specimens for sheet and strip may be of any suitable length over the above minimum length.

Section 11.—Revise to read as indicated above for Section 10 of Specifications A 167.

Standard Specifications for Corrosion-Resisting Chromium and Chromium-Nickel Steel Plate, Sheet, and Strip for Fusion-Welded Unfired Pressure Vessels (**A 240 – 49**).[2]

Table II.—Change the title to read "Mechanical Test Requirements."

Section 8.—Change the heading to read "Mechanical Properties." Reletter present Section as Paragraph (*a*); change "physical properties" to read "mechanical properties." Add new paragraph (*b*) to read as does Section 7 (*c*) of Specifications A 167.

Section 9 (b).—Revise to read as indicated above for Section 8 (*b*) of Specifications A 167.

Section 9 (c).—Revise to read as indicated above for Section 8 (*c*) of Specifications A 167.

Section 10 (a).—Revise to read as indicated above for Section 9 (*a*) of Specifications A 167.

Figure 1.—Delete.

Figure 2.—Delete.

Section 10 (b).—Revise to read as indicated above for Section 9 (*b*) of Specifications A 167.

Section 10 (c).—Insert new Paragraph (*c*), relettering subsequent Paragraphs accordingly as indicated above for Section 9 (*c*) of Specifications A 167.

Section 10 (f).—Revise to read as indicated above for Section 9 (*f*) of Specifications A 167.

Section 11.—Revise to read as indicated above for Section 10 of Specifications A 167.

RECOMMENDATIONS JOINTLY WITH COMMITTEE A-1

Committee A-10 joins with Committee A-1 on Steel in recommending the revision of Tentative Specifications for Seamless and Welded Austenitic Stainless Steel Pipe (**A 312 – 51 T**)[2] and the immediate adoption of revisions in the following standards, and accordingly requests the necessary nine-tenths vote at the Annual Meeting in order that these recommendations may be referred to letter ballot of the Society:

Standard Specifications for Seamless and Welded Ferritic Stainless Steel Tubing for General Service (**A 268 – 53**),[3]

Standard Specifications for Seamless and Welded Austenitic Stainless Steel Tubing for General Service (**A 269 – 52**),[2]

Standard Specifications for Seamless and Welded Austenitic Stainless Steel Sanitary Tubing (**A 270 – 50**),[2] *and*

Standard Specifications for Seamless Austenitic Chromium-Nickel Steel Still Tubes for Refinery Service (**A 271 – 53**).[3]

The revisions in Tentative Specifications A 312, and Specifications A 268, A 269, A 270, and A 271 are detailed in the report of Committee A-1.[4]

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[5]

ACTIVITIES OF SUBCOMMITTEES

Subcommittee IV on Methods of Corrosion Testing (F. L. LaQue, chairman).—A task group under the chairmanship of E. G. Holmberg prepared the recommended practice for descaling and cleaning stainless steel surfaces which is appended hereto.[1]

Another task group, under the chairmanship of C. P. Larrabee, has exposed nine compositions of stainless steel with two surface finishes at atmospheric test locations in Pittsburgh and New York City. The object is to develop data pertinent to the use of stainless steels in architectural applications in industrial atmospheres and especially to compare straight chromium, chromium-manganese, and chromium-nickel compositions.

Under the direction of M. H. Brown, boiling nitric acid tests were carried out on remnants of Charpy impact test specimens left from the studies of sigma phase and its identification undertaken by Subcommittee VI. The results indicated that the form and distribution of the sigma phase and associated carbides were more important than the amounts present in determining the severity of the attack. These data were turned over to Subcommittee VI for appropriate reference in their report of their investigations of sigma phase.

Under the chairmanship of K. M. Huston, a task group has prepared a draft of a procedure for carrying out the acidified copper sulfate test for intergranular corrosion of stainless steels. This is being circulated in the subcommittee for critical comment.

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[3] 1953 Supplement to Book of ASTM Standards, Part 1.

[4] See p. 97.

[5] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

A subgroup under the chairmanship of M. H. Brown prepared a footnote for Recommended Practice A 262 - 52 T (boiling nitric acid test) which calls attention to the high rates of corrosion that might be observed with certain grades of stainless steel (sensitized 316L, 316 Cb, and 321) due to causes other than carbide precipitation.

Another subgroup, also headed by M. H. Brown, prepared a draft of a proposed supplement to Recommended Practice A 262 - 52 T (boiling nitric acid test) which would provide for the use of the electrolytic oxalic acid etching technique as a means of screening lots of stainless steel so that those that passed the etching test would not need to be subjected to the boiling nitric acid test. This is being circulated in the Committee for approval by letter ballot. As a basis for this action, the results of round-robin tests on wrought alloys by several laboratories and on cast alloys by investigators for the Alloy Casting Institute at Ohio State University and in the laboratories of the Duriron Co. were published under sponsorship of Subcommittee IV in the February, 1954, issue of the ASTM BULLETIN.

The task group on inspection of architectural applications of stainless steel was reactivated under the chairmanship of J. B. Henry. This group has made an inspection of several installations and will submit a report at the time of the June meeting.

Progress has been made in working out final details of the large-scale program of atmospheric tests of stainless steels. Arrangements for procuring the specimen materials are being completed through the Stainless Steel Technical Committee of the American Iron and Steel Inst.

G. Kiefer was appointed to represent Subcommittee IV as a liaison member to Subcommittee XIV on Conditioning and Weathering of Committee E-1. This subcommittee is concerned with standardization of humidity cabinet tests.

Subcommittee V on Mechanical Testing (R. Heyer, chairman).—The Task Group on Tension Testing recommended that the cooperative tension tests on annealed, $\frac{1}{4}$ hard, and $\frac{1}{2}$ hard temper type 301 in two thicknesses be repeated, using a fixed straining rate of 0.4 in. per in. per min. A recommendation was also made for changing the gage length requirement for tension tests in Specifications A 276 - 49 T.

During the year the subcommittee reviewed the mechanical test requirements of the specifications for flat products and compiled a list of eighteen proposed changes in Specifications A 167, A 176, A 177, and A 240.

Subcommittee VI on Metallography (R. Franks, chairman).—A report of Subcommittee VI on the etching techniques for identification of the sigma phase in stainless steels was completed and published in the 1953 *Proceedings*.[6] This work consisted of the investigation of a number of different etching reagents on 18 per cent chromium - 8 per cent nickel steels with and without molybdenum. Certain samples of the steels contained the sigma phase as established by X-ray diffraction technique, while others contained none of the phase. The report gives data on etching procedures that can be safely used in identifying the sigma phase in stainless steels, provided the composition and thermal treatments of the steels are known. Further work in sigma phase identification will be undertaken as fresh approaches to the problem are indicated.

Subcommittee VIII on Specifications for Wrought Products (R. B. Gunia, chairman).—During the past year, Subcommittee VIII developed a number of revisions for Specifications A 276 - 49 T. A task group of this subcommittee has been assigned to review the problems encountered in the hardness testing of stainless bars.

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[6] "Experiments on Etching Procedures for the Identification of the Sigma Phase in Austenitic Chromium-Nickel Stainless Steels," Appendix to Report of Committee A-10, *Proceedings*, Am. Soc. Testing Mats., Vol. 53, p. 143 (1953).

Subcommittee IX on Specifications for Flat Products (G. W. Hinkle, chairman). —Several changes have been made in Specifications A 167, A 176, A 177, and A 240, bringing these specifications up to date. These include a change of tensile properties on type AISI 430, the inclusion of type 305 in Specifications A 167 and A 240, and the inclusion of types 304L and 316L with physical requirements in Specifications A 240. On Specifications A 167, A 176, and A 240 there has been a clarification of alternate methods for determining yield strength. The physical properties for types 403 and 410 in Specifications A 176 and A 240 have been clarified so that they now conform.

A "Basis of Purchase" section has been approved for Specifications A 167, A 176, and A 177. In Specifications A 240, sensitizing tests for types 321 and 347 have been established as to procedure and number of tests per shipment.

Subcommittee XII on Specifications for High-Temperature Super-Strength Alloys (L. L. Wyman, chairman).—Task groups have listed all super-strength alloys of possible interest and compiled a report on the chemical compositions and rupture properties of these alloys, as well as patent coverage wherever known. Portions of this report were incorporated in a Special Technical Publication[7] of the ASTM-ASME Joint Committee on Effect of Temperature on the Properties of Metals. Drafts of "prototypes"—that is, broad specifications of the kinds of tests that should be included in detailed product specifications for the three types of alloys, that is, (*a*) hot-cold worked, (*b*) precipitation-hardened, and (*c*) cast —have been circulated to all subcommittee members for comment.

Joint A-1–A-10 Subcommittee on Stainless Tubing Specifications (J. J. B. Rutherford, chairman).—The attention of this group has been directed to the activities of other committees that are interested in stainless tubular products. The pipe section of Subcommittee XXII of Committee A-1 on Steel is formulating a specification for seamless austenitic stainless pipe which will be designated expressly for high-temperature service. A task force from Subcommittees IX and XXII of A-1 is working on the subject of excessive testing. Numerous parties outside of the Society have registered concern with the 1951 change in Specifications A 312 which requires welding without filler metal. Their attention was directed to Specifications A 358, covering welded stainless pipe (this specification was also prepared outside of this subcommittee). A task force was established to study the heat-treating clauses in the various stainless tubular products specifications.

A letter ballot will be circulated in the subcommittee requesting approval of changes acted upon by Subcommittee IX of A-1, which represent general changes being made in all tubular products specifications.

This report has been submitted to letter ballot of the committee, which consists of 103 voting members; 92 members returned their ballots, of whom 85 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

JEROME STRAUSS,
Chairman.

M. A. CORDOVI,
Secretary.

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[7] See Appendix II, p. 206, "Report on the Elevated-Temperature Properties of Selected Super-Strength Alloys," Am. Soc. Testing Mats. (1954). (Issued as separate publication *ASTM STP No. 160*.)

REPORT OF COMMITTEE B-1

ON

WIRES FOR ELECTRICAL CONDUCTORS*

Committee B-1 on Wires for Electrical Conductors held three meetings during the year: one at the Society's headquarters in Philadelphia, Pa., on October 2, 1953; one in Washington, D. C., on February 2, 1954; and one in New York, N. Y., on April 13, 1954. Meetings of the Advisory Committee and of Subcommittees II, IV, and VII also were held during the year.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, D. Halloran.
Vice-Chairman, W. R. Hibbard.
Secretary, A. A. Jones.

Election of members at large of the Advisory Committee resulted in the selection of the following: L. B. Curtis, A. A. Defoe, M. F. W. Heberlein, R. H. Lloyd, and S. Skowronski.

The subcommittees' organization and their chairmen remained unchanged.

The committee now consists of 75 members, of whom 36 are classified as producers, 27 as consumers, and 12 as general interest members.

New Tentative

With the rapid growth of the electronics industry, there has been increasing usage of small insulated conductors specially suited for this application. However, there has been no uniformity of specification requirements among the various groups of users, including the Military. The committee recognized the need for standardization efforts in this field about two years ago and since then has developed a proposed specification in cooperation with the various interested groups, including the Radio-Electronics-Television Manufacturers' Assn., the Military, and producers of this product who were not previously represented in Committee B-1. The committee, therefore, recommends for publication as tentative the proposed Tentative Specifications for Soft or Annealed Coated Copper Conductors for Use in Hookup Wire for Electronic Equipment, as appended hereto.[1]

Revisions of Tentatives

The committee recommends that the following two specifications be revised as indicated and continued as tentative:

Tentative Specifications for Soft or Annealed Copper Wire (**B 3 - 53 T**).[2]—Revise as follows:

Explanatory Notes.—Delete the present Table IV and Note 9.

Tentative Specifications for Hard-Drawn Aluminum Wire for Electrical Purposes (**B 230 - 53 T**).[2]—Revise as follows:

Section 7.—At the end of the first paragraph change the present word "values" to read "value."

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13-18, 1954.

[1] The new tentative was accepted by the Society and appears in the 1954 Supplement to Book of ASTM Standards, Part 2.

[2] 1953 Supplement to Book of ASTM Standards, Part 2.

Delete Items (*1*) and (*2*) in their entirety and insert a new paragraph, reading "***Maximum** of All Measurements Representing Any One Lot*—17.002 ohms (mil, foot) at 20 C (68 F)."

Explanatory Note 2.—Delete the second paragraph, starting "The resistivity of aluminum conductor has been prescribed in Section 7 . . .," and insert a new paragraph, reading as follows:

> The resistivity of aluminum conductor has been prescribed in Section 7 on the basis of not less than 61.0 per cent of that of the International Annealed Copper Standard (IACS). The corresponding maximum resistivity values for aluminum are 0.076397 ohms (meter, gram) and 436.24 ohms (mile, pound).

Table II.—Delete the present data for aluminum (two lines) and insert new data (one line) as follows:

Volume Conductivity at 20 C (68 F), per cent IACS	61.0
Resistivity Constants at 20 C (68 F):	
Ohms (Mil, Foot)	17.002
Ohms (Meter, Square Millimeter)	0.028264
Microhms—Inch	1.1128
Microhms—Centimeter	2.8264
Ohms (Mile, Pound)	436.24
Ohms (Meter, Gram)	0.076397

REAFFIRMATION OF TENTATIVES

The Committee recommends that the following four specifications be reaffirmed and continued as tentative:

Tentative Specifications for Standard Weight Zinc-Coated (Galvanized) Steel Core Wire for Aluminum Conductors, Steel Reinforced (ACSR) (**B 245 – 52 T**).[3]

Tentative Specifications for Tinned Hard-Drawn and Medium-Hard-Drawn Copper Wire for Electrical Purposes (**B 246 – 51 T**).[3]

Tentative Specifications for Standard Nominal Diameters and Cross-Sectional Areas of AWG Sizes of Solid Round Wires Used as Electrical Conductors (**B 258 – 51 T**),[3] and

Tentative Specifications for Zinc-Coated (Galvanized) Steel Core Wire (With Coatings Heavier than Standard Weight) for Aluminum Conductors, Steel Reinforced (ACSR) (**B 261 – 52 T**).[3]

REVISIONS OF STANDARDS, IMMEDIATE ADOPTION

The committee recommends, for immediate adoption, revisions in the following two standards and accordingly asks for a nine-tenths affirmative vote at the Annual Meeting in order that these recommendations may be referred to letter ballot of the Society.

Standard Specifications for Concentric-Lay-Stranded Aluminum Conductors, Hard-Drawn (**B 231 – 53**).[2]—Revise as follows:

Title.—Add at the end of the present title the words "and Three-Quarter Hard-Drawn."

Section 1(a).—Revise to read as follows:

> (*a*) These specifications cover concentric-lay-stranded conductors made of round aluminum wires, either hard-drawn or three-quarter hard-drawn, for general use for electrical purposes.

Section 1(b).—Add to the end of the present paragraph describing the uses of class A conductors, a new sentence reading "Conductors intended for further fabrication into tree wire or to be insulated and laid helically with or around aluminum or ACSR messengers, shall be regarded as class A conductors with respect to direction of lay only (See Section 5(*d*))."

Section 2.—Renumber Item (*4*) to be Item (*5*) and renumber all subsequent items accordingly. Insert a new Item (*4*) to read "(*4*) Temper (Sections 3(*a*) and 3(*c*))."

Section 3.—Revise to read as follows:

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[3] 1952 Book of ASTM Standards, Part 2.

3. (*a*) Aluminum wire employed in classes AA and A conductors shall be hard-drawn, unless otherwise specified. The purchaser shall designate the temper of aluminum wire to be used in conductors of classes B, C, and D.

(*b*) Before stranding, the aluminum wires used shall conform to all the requirements of the following standard specifications of the American Society for Testing Materials that are applicable to its type:

Tentative Specifications for Hard-Drawn Aluminum Wire for Electrical Purposes (ASTM Designation: B 230), and

Tentative Specifications for Three-Quarter Hard Aluminum Wire for Electrical Purposes (ASTM Designation: B 262).

(*c*) In concentric-lay stranded conductors the central core shall be made of wire of the same temper as the concentric layers, unless otherwise specified.

TABLE I.—CONDUCTOR SIZES AND STRANDINGS TO BE ADDED TO TABLE II IN SPECIFICATIONS B 231.

Conductor Size, cir mils	Hard-Drawn Copper Equivalent, cir mils or Awg	Class AA		Class A	
		Number of Wires	Diameter of Wire, mils	Number of Wires	Diameter of Wire, mils
636 000........	400 000	37	131.1	37	131.1
477 000........	300 000	19	158.4	37	113.5
336 400........	0000	12	167.4	19	133.1
266 800........	000	12	149.1	19	118.5

Table II.[4]—Add to the present Table II, in proper size sequence, new conductor sizes and strandings, to read as shown in the accompanying Table I.

Add a new Footnote *a* referenced in column 1 of Table II after sizes 1,600,000; 1,250,000; 800,000; and 400,000 cir mils, to read as follows:

These sizes are sensibly equivalent to sizes 1,590,000; 1,272,000; 795,000; and 397,500 cir mils respectively within the cross-sectional area tolerances stipulated by these specifications and associated ASTM Specifications B 230 and B 262.

Add a new Footnote *b* referenced in column 1 of Table II after size 1,000,000 cir mils, to read as follows:

This size is sensibly equivalent to size 1,033,500 cir mils within a difference of 3.24 per cent.

Section 7(*b*).—Delete the present second and third sentences and replace with new sentences, reading as follows:

The minimum breaking strength of hard-drawn and three-quarter hard-drawn bare conductors so tested shall be at least 90 per cent of the total of the calculated minimum breaking strengths of the component wires. The minimum breaking strengths of the component wires shall be calculated using specified nominal wire diameters and specified minimum average tensile strengths in the case of hard-drawn aluminum conductors, or specified minimum tensile strengths in the case of three-quarter hard-drawn conductors. The maximum breaking strength of conductors made from three-quarter hard wires shall be not greater than the sum of the calculated maximum breaking strengths of the component wires. The maximum breaking strengths of the component wires shall be calculated using specified nominal wire diameters and specified maximum tensile strengths.

Section 7(*c*).—Delete the present second sentence and replace with a new second sentence, reading as follows:

When so tested hard-drawn wires shall have minimum tensile strengths not less than 95 per cent of the tensile strengths prescribed for individual tests in Table I of the Tentative Specifications for Hard-Drawn Aluminum Wire for Electrical Purposes (ASTM Designation: B 230),[2] and three-quarter hard-drawn wires shall have tensile strengths not less than 95 per cent of the minimum tensile strength nor more than 105 per cent of the maximum tensile strength prescribed in Section 5(*a*) of the Tentative Specifications for Three-Quarter Hard Aluminum Wire for Electrical Purposes (ASTM Designation: B 262).[2]

Revise the beginning of the present third sentence, to read "For hard-drawn aluminum wires removed from completed conductors, the elongation in a 10-in. length shall . . .”

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[4] The committee took a vote of preference on two alternative proposed actions with regard to conductor sizes included in Table II, as follows:

1. Retain the present 400,000 cir mil size listing in all stranding classes.
2. Delete the present 400,000 cir mil size listing and replace with 397,500 cir mil size listing in stranding classes AA and A. Retain the present 400,000 cir mil size listing in classes B, C, and D.

The resulting vote was in favor of proposal 1.

TABLE II.—RESISTIVITY REQUIREMENTS.

Type	Resistivity, ohms (mile, pound), max
EC-H16	434.10
EC-H14	433.39
EC-H12	432.69
EC-O	430.59
EC-H12-B	432.69

Standard Specifications for Rolled Aluminum Rods (EC Grade) for Electrical Purposes (**B 233 – 52**).[3]—Revise as follows:

Section 5(*a*).—Revise to read as follows:

> (*a*) Resistivity shall be determined on representative samples by resistance measurements (Note 3). At a temperature of 20 C (68 F), the resistivity of the various types shall not exceed the values shown in Table II (Note 3).

New table.—Add a new Table II to read as shown in the accompanying Table II, renumbering subsequent tables accordingly.

Explanatory Note 3.—Delete the second paragraph in its entirety.

Table III.—Renumber as Table IV, delete the present data for aluminum (2 lines), and insert new data (4 lines), to read as shown in the accompanying Table III.

TABLE III.—EQUIVALENT RESISTIVITY VALUES.

Material	Volume Conductivity, per cent	Resistivity Constants at 20 C. (68 F.)					
		Weight		Volume			
		Ohms (mile, pound)	Ohms (meter, gram)	Ohms (mil, foot)	Ohms (meter, square millimeter)	Microhms—inch	Microhms—centimeter
Copper	100	875.20	0.15328	10.371	0.017241	0.67879	1.7241
Aluminum	61.3	434.10	0.076025	16.919	0.028126	1.1073	2.8126
	61.4	433.39	0.075901	16.891	0.028080	1.1055	2.8080
	61.5	432.69	0.075778	16.864	0.028035	1.1037	2.8035
	61.8	430.59	0.075410	16.782	0.027899	1.0983	2.7899

EDITORIAL REVISIONS

The committee took action during the year to make editorial revisions in the following eight specifications:

Tentative Specifications for Hard-Drawn Copper Wire (**B 1 – 53 T**).[2]—Revise as follows:

Section 7(a) Tensile Strength.—Retain the present first paragraph without change. Delete the present second paragraph and insert new second and third paragraphs to read as follows:

> The lot shall be considered to have failed to meet the tensile conformance criterion if the average of the four specimens is less than the tensile strength in Table I minus 400 psi *and* the tensile strength of any of the individual specimens is less than the value in Table I minus 1700 psi.
>
> If the average of the four specimens is less than the tensile strength in Table I minus 400 psi and the tensile strength of each of the individual specimens is equal to or more than the value in Table I minus 1700 psi, six additional specimens from six production units other than the four originally sampled, shall be tested. The lot shall be considered conforming if the tensile strength of each of the ten specimens is not less than the appropriate tensile strength value in Table I minus 1700 psi and the average of the ten specimens is not less than the value in Table I minus 400 psi. The lot shall be considered to have failed to meet the tensile strength require-

ment if the tensile strength of any of the individual specimens is less than the value in Table I minus 1700 psi or if the average of the ten specimens is less than the value in Table I minus 400 psi.

Section 7(b) Elongation.—Retain the present first paragraph without change. Delete the present second paragraph and insert new second and third paragraphs to read as follows:

> The lot shall be considered to have failed to meet the elongation conformance criterion, if the average of the four specimens is less than the appropriate elongation value in Table I minus 0.05 per cent *and* the elongation of any of the individual specimens is less than the elongation value in Table I minus 0.20 per cent.
>
> If the average of the four specimens is less than the appropriate elongation value in Table I minus 0.05 per cent and the elongation of each of the individual specimens is equal to or more than the elongation value in Table I minus 0.20 per cent, six additional specimens from six production units other than the four originally sampled, shall be tested. The lot shall be considered conforming if the elongation of each of the ten specimens is not less than the appropriate elongation value in Table I minus 0.20 per cent and the average of the ten specimens is not less than the value in Table I minus 0.05 per cent. The lot shall be considered to have failed to meet the elongation requirement if any of the ten specimens is less than the appropriate elongation value in Table I minus 0.20 per cent or if the average of the ten specimens is less than the elongation value in Table I minus 0.20 per cent.

Tentative Specifications for Soft or Annealed Copper Wire (**B 3 - 53 T**).[3]—Revise as follows:

Section 7(a) Tensile Strength.—In the first paragraph, first sentence, third line, change the present words "of the specimens" to read "of the four specimens." Delete the present second paragraph and insert new second and third paragraphs to read as follows:

> The lot shall be considered to have failed to meet the tensile conformance criterion if the average of the four specimens is more than the tensile strength in Table I minus 800 psi *and* the tensile strength of any of the individual specimens is more than the value in Table I.
>
> If the average of the four specimens is more than the tensile strength in Table I minus 800 psi and the tensile strength of each of the individual specimens is equal to or less than the value in Table I, six additional specimens from six production units, other than the four originally sampled, shall be tested. The lot shall be considered conforming if the tensile strength of each of the ten specimens is not more than the appropriate tensile strength value in Table I and the average of the ten specimens is not more than that value minus 800 psi. The lot shall be considered to have failed to meet the tensile strength requirement if any of the ten specimens exceeds the appropriate tensile strength value in Table I or if the average of the ten specimens exceeds that value minus 800 psi.

Section 7(b) Elongation.—Retain the present first paragraph without change. Delete the present second paragraph and insert new second and third paragraphs to read as follows:

> The lot shall be considered to have failed to meet the elongation conformance criterion if the average of the four specimens is less than the elongation in Table I plus 2.5 per cent *and* elongation of any of the individual specimens is less than the value in Table I.
>
> If the average of the four specimens is less than the elongation in Table I plus 2.5 per cent and the elongation of each of the individual specimens is equal to or more than the value in Table I, six additional specimens from six production units, other than the four originally sampled, shall be tested. The lot shall be considered conforming if the elongation of each of the ten specimens is not less than the appropriate elongation value in Table I, and the average of the ten specimens is not less than that value plus 2.5 per cent. The lot shall be considered to have failed to meet the elongation requirement if any of the ten specimens is less than the appropriate elongation value in Table I or if the average of the ten specimens is less than that value plus 2.5 per cent.

Standard Specifications for Concentric-Lay-Stranded Copper Conductors, Hard, Medium-Hard, or Soft (**B 8 - 53**).[2]—Revise as follows:

Section 7(f).—In the third sentence, change the present words "using nominal specified diameters and maximum specified tensile strengths" to read "using specified nominal diameters and specified maximum tensile strengths." In the fourth sentence, change the present words "shall not be less" to read "shall be not less."

Section 8(b).—In the fourth sentence, change the present words "using nominal specified diameters and minimum specified tensile strengths" to read "using specified nominal diameters and specified minimum tensile strengths." In the fifth sentence, change the present words "and maximum specified tensile strengths," to read "and specified maximum tensile strengths."

Standard Specifications for Bronze Trolley Wire (**B 9 - 53**).[2]—Revise as follows:

Table I.—In the first and second columns, delete the present diameter and area figures and replace with new values, as follows:

Diameter, in.	Area, cir mils
0.5477	300 000
0.4600	211 600
0.4096	167 800
0.3648	133 100
0.3249	105 600

Table II.—In the first column, make the same changes in diameter values as indicated above for Table I.

Fig. 1.—In the tabular data below the figure, for the nominal sizes, change the present "133,200" to read "133,100" cir mils and change the present "168,100" to read "167,800" cir mils.

Standard Specifications for Copper Trolley Wire (**B 47 - 52**).[3]—Revise as follows:

Table I.—Revise as indicated above for Table I in Specifications B 9.

Table II.—In the first column for Nominal Area, change the present "168,100" to read "167,800" cir mils and change the present "133,200" to read "133,100".

Figure 1.—Revise as indicated above for Fig. 1 in Specifications B 9.

Standard Specifications for Soft Rectangular and Square Bare Copper Wire for Electrical Conductors (**B 48 - 52**).[3]—Revise as follows:

NOTE 1.—In the first sentence, change the present words "Soft or annealed copper wire is wire which has been drawn to" to read "Soft or annealed copper wire is wire which has been drawn or rolled to."

Standard Specifications for Figure-9 Deep-Section Grooved and Figure-8 Copper Trolley Wire for Industrial Haulage (**B 116 - 52**).[3]—Revise as follows:

Table I.—Revise as indicated above for Table II in Specifications B 47.

Figure 1.—Revise as indicated above for Fig. 1 in Specifications B 9.

Tentative Specifications for Standard Nominal Diameters and Cross-Sectional Areas of AWG Sizes of Solid Round Wires Used as Electrical Conductors (**B 258 - 51 T**).[3]—Revise as follows:

Section 3.—Delete the present Section 3 and replace with a new Section 3 reading as follows:

> 3. All calculations for the standard nominal dimensions and properties of solid round wires shall be rounded off in the *final* value only, in accordance with rounding-off method of the Recommended Practices for Designating Significant Places in Specified Limiting Values (ASTM Designation: E 29).[3]

Section 5.—In the first paragraph, in the formula for Area, sq. in., delete the symbol "$<$" between d^2 and 0.7854 and replace with the symbol "$\times$".

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[4]

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[4] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Editorial and Records (A. A. Jones, chairman) continued its editorial review of specifications and coordinated the various subcommittee recommendations regarding revisions of the various specifications.

Subcommittee II on Methods of Test and Sampling Procedures (J. B. Dixon, chairman) completed editorial revision of Specifications B 1 and B 3 to clarify conformance criteria, is developing statistical sampling procedures for tinned- and alloy-coated copper, and is continuing its assignments to formulate a standard method of calculating lay factor (weight increment) for inclusion in the Tentative Method for Determination of Cross-Sectional Area of Stranded Conductors (ASTM Designation: B 263)[2] and to develop an alternate method (to the bell method) of measuring elongation in 60-in. gage length (for HD and MHD wire).

Subcommittee IV on Conductors of Copper and Copper Alloys (B. J. Sirois, chairman) completed preparation of the proposed Tentative Specifications for Soft or Annealed Coated Copper Conductors for Use in Hookup Wire for Electronic Equipment, and revision of Specifications B 3 deleting outmoded package sizes.

Task groups are working on the preparation of proposed Tentative Specifications for Silver-Coated Copper Wire; collecting test data on commercial production of soft, square and rectangular copper wire, to be used as a basis for establishing acceptance limits when tested in accordance with the Tentative Method of Test for Stiffness of Bare Soft Square and Rectangular Copper Wire for Magnet Wire Fabrication (ASTM Designation: B 279);[2] considering the advisability of incorporating in Specifications B 105 an additional alloy 30 consisting of 89 per cent copper, 0.5 per cent tin, balance zinc; and developing rules and formulas for computing derived data for shaped wire for inclusion in Specifications B 48.

Subcommittee VII on Conductors of Light Metals (P. V. Faragher, chairman) has completed revisions of Specifications B 230, B 231, and B 233, is working on the standardization of additional constructions of ACSR conductors, and is considering preparation of a proposed specification for annealed or one-quarter hard aluminum wire for telephone cable applications, and development of specifications for aluminum wire to be used in magnet wire.

This report has been submitted to letter ballot of the committee, which consists of 75 members; 60 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

D. HALLORAN,
Chairman.

A. A. JONES,
Secretary.

REPORT OF COMMITTEE B-2

ON

NON-FERROUS METALS AND ALLOYS*

Committee B-2 on Non-Ferrous Metals and Alloys has not held a meeting since its meeting in Atlantic City, N. J., on July 1, 1953. During the past year the work of the committee has been handled by correspondence. A meeting of the Advisory Committee was held on November 23, 1953, in New York City.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, Bruce W. Gonser.
Secretary, G. Howard LeFevre.

RECOMMENDATIONS ACCEPTED BY THE ADMINISTRATIVE COMMITTEE ON STANDARDS

Subsequent to the 1953 Annual Meeting, Committee B-2 presented to the Society through the Administrative Committee on Standards a Tentative Specification for Rosin Flux Cored Solder (B 284 - 53 T).

The specification was accepted by the Standards Committee on November 9, 1953, and it appears in the 1953 Supplement to Book of ASTM Standards, Part 2.

At this time the committee has no recommendations to present to the Society in connection with standards or tentatives under its jurisdiction.

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Refined Copper (William E. Milligan, chairman) has organized a task group to consider proposed revisions of the Tentative Specification B 72 - 47 T for Fire-Refined Casting Copper. The proposed revision of Specification B 4 - 42 for Lake Copper Wire Bars, Cakes, Slabs, Billets, Ingots, and Ingot Bars, as submitted by the task group, failed acceptance in letter ballot of the subcommittee. The task group, at a subsequent meeting, recommended to the subcommittee that there be no revision of Specification B 4 - 42 all the time.

Subcommittee II on Refined Lead, Tin, Antimony and Bismuth (Sidney Rosti, chairman) has work under way in a task group on the preparation of a Classification of Tin.

Subcommittee III on White Metals and Alloys (G. H. Clamer, chairman) completed work on the proposed Specification for Rosin Flux Cored Solder, which, as stated previously in the report, has been accepted by the Administrative Committee on Standards.

Subcommittee VI on Coated Metals (F. L. Scovill, Jr., chairman) through a task group continues the study of methods of test for continuity of coating of lead-coated copper sheets under Specification B 101 - 40.

Subcommittee VII on Refined Nickel and Cobalt, High-Nickel Alloys and High-Cobalt Alloys, Cast and Wrought (O. B. J. Fraser, chairman) has under review the specifications under its jurisdiction, and the subcommittee expects to submit recommendations shortly with respect to a number of specifications.

*** Presented at the Fifty-seventh Annual Meeting of the Society, June 13–18, 1954.**

Subcommittee VIII on Miscellaneous Refined Metals and Alloys (E. E. Schumacher, chairman) deferred action on recommending the adoption as standard of the Tentative Specifications for Iodide Titanium (B 266 - 52 T); Titanium Strip, Sheet, Plate, Bar, Tube, Rod and Wire (B 265 - 52 T); and Titanium Ingot (B 264 - 52 T). The information now in hand for any required revision of these specifications is not as yet complete. The task group is considering a proposed tentative specification for sponge titanium.

This report has been submitted to letter ballot of the committee, which consists of 134 members; 112 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

BRUCE W. GONSER,
Chairman.

G. HOWARD LEFEVRE,
Secretary.

REPORT OF COMMITTEE B-3

ON

CORROSION OF NON-FERROUS METALS AND ALLOYS*

Committee B-3 on Corrosion of Non-Ferrous Metals and Alloys held two meetings during the past year: one in Atlantic City, N. J., on June 2, 1953, and the other in Washington, D. C., on February 4, 1954.

The committee consists of 102 members, of whom 84 are voting members; 36 are classified as producers, 30 as consumers, and 18 as general interest members.

The following officers were elected for the ensuing term of two years:

Chairman, K. G. Compton.
Vice-Chairman, E. K. Camp.
Secretary, A. W. Tracy.

New Tentative

The committee recommends for publication as tentative the Method of Acetic Acid-Salt Spray (Fog) Testing as appended thereto.[1]

Revisions of Tentative

The committee recommends that the Tentative Method for Salt Spray (Fog) Testing (**B 117 - 49 T**)[2] be revised as follows and continued as tentative:

Section 4(a).—In the first sentence, change "freed from water break by suitable cleaning" to "suitably cleaned."

Section 5(a).—In line 3, change "approximately 15 deg" to "between 15 and 30 deg."

Section 6.—In line 2, change "20 ± 2" to "5 ± 1." In line 3, following "distilled water," add the words "or water." In line 9, change "0.2" to "0.3."

In Note 1, change "1.126 to 1.157" to "1.0268 to 1.0413."

Section 8(b).—In line 16, change "20 ± 2 per cent" to "5 ± 1 per cent."

In Note 2, line 2, change "1.126 to 1.157" to "1.0268 to 1.0413." In lines 3 and 4, delete the words "or from 1.130 to 1.162 at 75 F." In line 14, change "17.7 and 22.1" to "4.4 and 5.5."

Section 13.—In Paragraph (*c*)(*2*), delete the words "(or 75 F)."

Appendix I, Types of Apparatus.—In the first paragraph, second sentence, delete the word "aluminum" and after "monel" delete the word "metal." In the last sentence, delete "suitable" at the beginning of the sentence and insert the word "suitable" before "rubber."

In the sixth and seventh paragraphs, change "84 to 90 per cent" to "95 to 98 per cent."

Appendix I, Temperature Control.—In Paragraph (4), change "84 to 90 per cent" to "95 to 98 per cent." Change the table to read as follows:

	Air Pressure, psi			
	12	14	16	18
Temperature, deg., F.	114	117	119	121

Tentatives Continued without Revision

The committee recommends that the following two test methods be continued as tentative without change:

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13–18, 1954.

[1] The new tentative was accepted by the Society and appears in the 1954 Supplement to Book of ASTM Standards, Part 2.

[2] 1952 Book of ASTM Standards, Part 2.

Tentative Method of:

Total Immersion Corrosion Test of Non-Ferrous Metals (B 185 – 43 T), and
Alternate Immersion Corrosion Test of Non-Ferrous Metals (B 192 – 44 T).

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[3]

ACTIVITIES OF SUBCOMMITTEES

Subcommittee III on Spray Test (C. O. Durbin, chairman) has prepared the revision of the Tentative Method of Salt Spray (Fog) Testing (B 117 – 49 T) which consists essentially in reducing the salt concentration from 20 per cent to 5 per cent. This change was proposed because more reproducible results were obtained with the 5 per cent solution due to the higher relative humidity and freedom from nozzle clogging by salt crystals in the spray frequently encountered with the 20 per cent solution. A survey of the literature indicated that the 20 per cent solution was less sensitive to temperature variations than the 5 per cent solution. However, it was felt that this was less important than the effect of the salt crystals in the spray and nozzle clogging.

A task group headed by W. B. McMaster has been conducting tests on the acetic acid modification of the salt spray (fog) test.[4] These tests show that materials normally tested by the salt spray (fog) test may also be tested by the acetic acid modification. The time required for failure will usually be shorter in the acetic acid modification of the salt spray (fog) test. The subcommittee decided that this test had sufficient merit to recommend its publication as tentative.

Subcommittee VI on Atmospheric Corrosion (W. H. Finkeldey, chairman), through a task group, is working on the weighing and tension testing of specimens exposed for 20 years to the atmosphere at several ASTM test sites. The program includes tension tests on specimens machined before exposure and specimens cut from cleaned 9 by 12-in. plates after removal from exposure. The subcommittee expects to have a final report prepared for use in working up a symposium on atmospheric corrosion for the 1955 Annual Meeting.

Subcommittee VII on Weather (F. L. LaQue, chairman).—A task group has continued its program of calibrating the corrosivity of various atmospheric test sites. The program will terminate in 1956.

In 1954 and 1955 specimens will be exposed at seven test sites being used for atmospheric corrosion tests by the National Research Council of Canada.

L. G. von Lossberg has been appointed to represent Subcommittee VII on Committee D-22, which is concerned with methods of atmospheric sampling and analysis.

Subcommittee VIII on Galvanic and Electrolytic Corrosion (Gerald Kingsley, chairman) has continued its program of tests on magnesium coupled to other metals and exposed at several ASTM test sites. The couples made by winding wires of one metal in the grooves of threaded spools of the other metal have been exposed and brought in for examination. The test results have been evaluated[5] by A. Mendizza of the Bell Telephone Laboratories, Inc., as a report of the subcommittee.

A working group under the chairmanship of H. O. Teeple, The International Nickel Co., Inc., has examined the first set of disk couples removed from exposure, and weight loss data are being evaluated.

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[3] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

[4] W. D. McMaster, "The Five Per Cent Salt Spray and Its Acetic Acid Modification," ASTM BULLETIN, No. 203, January, 1955, p. 62 (TP 22).

[5] See p. 150.

Another task group is working on the third part of the program for which galvanic couples will be made by fastening bars of other metals to magnesium plates and the extent of galvanic corrosion in the atmosphere determined by tension tests on specimens machined from the exposed panels. C. Walton of the Aluminum Company of America is making preliminary tests to determine the form of couple to give best results.

This report has been submitted to letter ballot of the committee, which consists of 84 voting members; 62 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

K. G. Compton,
Chairman.

A. W. Tracy,
Secretary.

REPORT OF SUBCOMMITTEE VIII ON GALVANIC AND ELECTROLYTIC CORROSION

SPOOL-AND-WIRE COUPLE TESTS—PART II OF A THREE-PART PROGRAM[1]

An investigation of the galvanic corrosion of dissimilar metal couples exposed to various atmospheric conditions is being conducted by Subcommittee VIII on Galvanic and Electrolytic Corrosion of ASTM Committee B-3. The following report is part of a larger program directed by the committee and involves the investigation of bimetallic couples consisting of a wire (usually the anode) wound around a threaded spool (the cathode).

These tests were set up to evaluate in a preliminary fashion the effectiveness of this type of couple arrangement. A brief description of the couple make-up follows.

The couple is formed by a $\frac{1}{2}$-in. diameter threaded spool around which the other metal, as wire, is tightly wound. The wire ends are held by brass screws in lugs on the spool; this insures continuous electrical contact between wire and spool even if corrosion products are formed along the wound length of wire. The end sections of wire not in contact with the spool, the lugs, and the screws are painted with an acid-resisting black varnish to protect them from atmospheric corrosion and to insulate the main part of the wire from any galvanic action at the fastenings. Approximately 30 in. of wire is in intimate contact with the spool, in a span of 2 in. The total length of the spool is 4 in. A couple being assembled is shown in Fig. 1. A detailed description of the method of assembly is found in Appendix I.

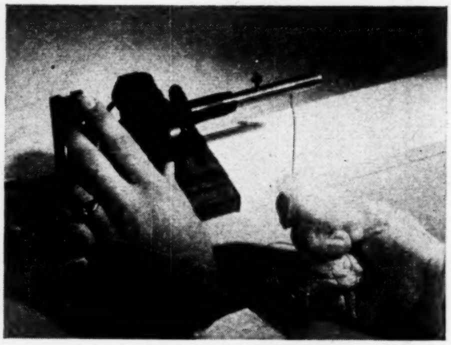

FIG. 1.—Winding Wire onto Spool.

Magnesium was tested in contact with magnesium, aluminum, brass, and zinc. Couples were exposed with magnesium as both spool and wire. In addition, each metal was also exposed in contact with itself as a control couple. All couples were exposed in triplicate. The following couples were studied:

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[1] This report summarizes a part of the work in the corrosion field sponsored by ASTM Committee B-3 on Corrosion of Non-Ferrous Metals and Alloys. Data from Parts I and III not yet available.

Couple	Wire Alloy	Spool Alloy
Nos. 1, 2, 3	Magnesium AZ31X	Magnesium AZ31X
Nos. 4, 5, 6	Magnesium AZ31X	85-15 Brass
Nos. 7, 8, 9	Magnesium AZ31X	Zinc
Nos. 10, 11, 12	Magnesium AZ31X	Magnesium M1
Nos. 13, 14, 15	Magnesium AZ31X	Aluminum 56S
Nos. 16, 17, 18	Magnesium AZ31X	Aluminum 2S
Nos. 19, 20, 21	85-15 Brass	Magnesium AZ31X
Nos. 22, 23, 24	Zinc	Magnesium AZ31X
Nos. 25, 26, 27	Magnesium M1	Magnesium AZ31X
Nos. 28, 29, 30	Aluminum 56S	Magnesium AZ31X
Nos. 31, 32, 33	Aluminum 2S	Magnesium AZ31X
Nos. 34, 35, 36	85-15 Brass	85-15 Brass
Nos. 37, 38, 39	Zinc	Zinc
Nos. 40, 41, 42	Magnesium M1	Magnesium M1
Nos. 43, 44, 45	Aluminum 56S	Aluminum 56S
Nos. 46, 47, 48	Aluminum 2S	Aluminum 2S

An analysis of the various metals appears in Appendix II.

Three exposure sites were employed in order to investigate the effects of differing atmospheres on galvanic corrosion.

1. New York, N. Y., representative of a large city, with industrial fumes and smoke, and some salt fog.

2. Kure Beach, N. C., representative of clean sea air.

3. State College, Pa., representative of clean inland air, free of industrial fumes and salt spray.

The couples were mounted on racks exposed in a horizontal position, each holding one complete set. There were four exposure periods at each site: the first, a full year; and the second, third, and fourth, consecutive four-month portions of the same year. This plan was expected to indicate the effects of initial exposure on eventual corrosion. The actual exposure dates for each site were:

Site	First Period	Second Period	Third Period	Fourth Period
New York	12/6/51 to 1/14/52	12/6/51 to 4/4/52	4/4/52 to 8/14/52	8/14/52 to 1/14/52
Kure Beach	12/22/51 to 12/22/52	12/22/51 to 5/27/52	5/27/52 to 8/12/52	8/12/52 to 12/22/52
State College	12/18/51 to 12/–/52	12/18/51 to 5/6/52	5/6/52 to 8/11/52	8/11/52 to 12/–/52

It will be noted that the actual periods varied from the nominal in some cases; this was due to unavoidable delays in shipping. No correction for these variations has been attempted in plotting the data.

The total number of couples in this study was 576.

After exposure, the wires were examined for breaks, and resistance measurements were made to determine electrical continuity. The AZ31X magnesium wire was found broken, apparently because of stress corrosion in almost every case. These breaks occurred on some couples within a month of their exposure. The notable exceptions to this occurred in most cases where AZ31X magnesium wire was exposed in contact with M1 magnesium spools and for the third exposure period at Kure Beach. However, good electrical contact between the wire sections and the spools was maintained in most instances, excepting for the 1-yr specimens. It was also noted that the varnish used provides inadequate protection for some of the exposure conditions. In most of these cases the end pieces, particularly of the magnesium wire, had been seriously attacked, or even completely lost. Electrical contact for the remainder of the wire frequently was maintained, however, permitting obtainment of weight loss data. Figure 2, a view of some of the couples exposed at State College for 1 yr, shows the types of wire breaks encountered (couples 1 to 7). Good electrical contact still existed in all but couples 1 and 7. In these two cases about a fourth of the wire was not in contact. However, weight loss measurements in both cases were comparable with those obtained for the duplicates of these couples.

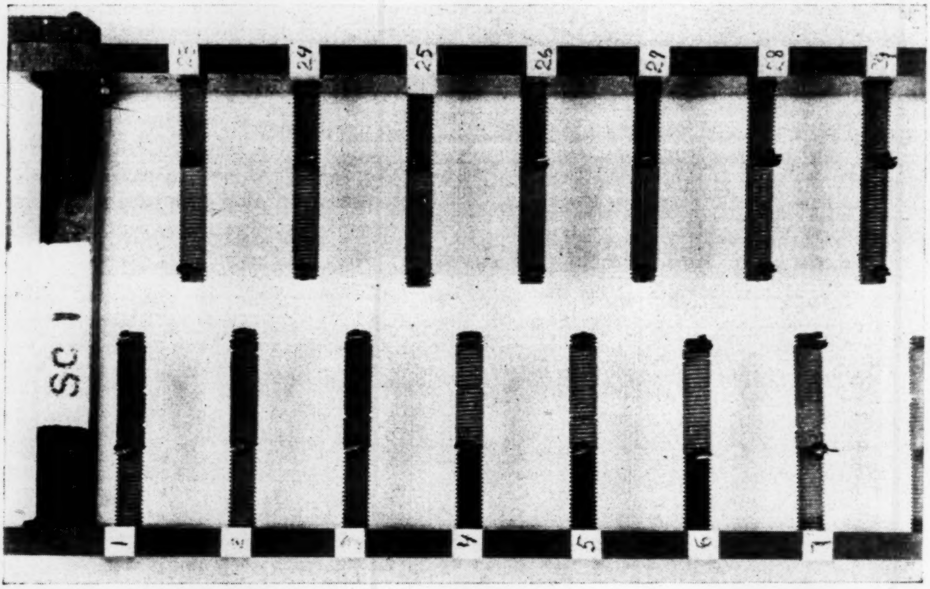


FIG. 2.—Some Couples Exposed at State College for One Year, Showing Types of Wire Breaks Encountered.

After examination the couples were carefully disassembled and the wires cleaned and weighed. The cleaning procedures employed are described in Appendix II. Losses due to cleaning were found to be negligible and have not been incorporated in the weight loss calculations. A sample data sheet is included in Appendix IV.

Results:

The results of this study are presented in Table I as total average per cent weight loss for each couple combination, for four exposure periods, at three sites. Weight losses for brass, zinc, and aluminum wires exposed on AZ31X magnesium spools were very small, and, except for slight deviations for some aluminum wires, the losses were smaller than for the control couples. In general, therefore, brass, zinc, and aluminum

TABLE I.—TOTAL PER CENT WEIGHT LOSS.
Average of 3 Samples

Couple			First Period			Second Period			Third Period			Fourth Period		
	Wire	Spool	New York	Kure Beach	State College	New York	Kure Beach	State College	New York	Kure Beach	State College	New York	Kure Beach	State College
Nos. 1 to 3	AZ31X Mg	AZ31X Mg	12.4[a]	4.3[a]	5.8[b]	4.3[b]	2.0[b]	3.4[b]	4.2[b]	0.9	1.6	4.0[b]	3.9[b]	2.9
Nos. 4 to 6	AZ31X Mg	85-15 Brass	41.1[b]	30.6[b]	24.5[b]	16.4[b]	14.1[b]	11.3[b]	16.3[b]	13.1	6.8[b]	18.0[b]	21.9[b]	14.5[b]
Nos. 7 to 9	AZ31X Mg	Zinc	28.8[a]	16.7[b]	15.1[b]	10.3[b]	7.6[b]	6.8[b]	9.4[b]	6.3	4.0[b]	10.7[b]	12.6[b]	8.1[b]
Nos. 10 to 12	AZ31X Mg	M1 Mg	2.7[a]	2.1[a]	1.4	1.6[b]	0.7	0.4	1.2	0.6	0.6	1.8	1.3[b]	1.6
Nos. 13 to 15	AZ31X Mg	56S Al	25.2[a]	8.9[a]	12.8[b]	9.9[b]	4.2[b]	5.7[b]	8.3[b]	2.3	2.6[b]	10.0[b]	8.4[a]	5.9[b]
Nos. 16 to 18	AZ31X Mg	2S Al	26.0[a]	9.4[a]	14.0[b]	12.0[b]	5.0[b]	5.9	8.1[b]	3.1[b]	2.5[b]	11.2[b]	9.6[a]	5.8[b]
Nos. 19 to 21	85-15 Brass	AZ31X Mg	0.1	0.1	0.1	0.02	0.03	0.05	0.09	0.01	0.05	0.2	0.1	0.1
Nos. 22 to 24	Zinc	AZ31X Mg	0.8	0.7	0.3	0.3	0.3	0.2	0.4	0.3	0.2	0.4	0.7	0.2
Nos. 25 to 27	M1 Mg	AZ31X Mg	25.7[a]	10.0[a]	15.8	11.4	5.6	8.0	10.6	2.9	4.9	11.4	8.3[b]	7.3
Nos. 28 to 30	56S Al	AZ31X Mg	0.3	0.5	0.2	0.07	0.2	0.08	0.09	0.2	0.2	0.3	0.8	0.3
Nos. 31 to 33	2S Al	AZ31X Mg	0.1	0.3	0.1	0.06	0.05	0.0	−0.08	0.2	0.07	0.1	0.4	0.03
Nos. 34 to 36	85-15 Brass	85-15 Brass	0.9	0.7	0.3	0.2	0.3	0.1	0.2	3.4	0.07	0.4	0.6	0.2
Nos. 37 to 39	Zinc	Zinc	3.2	1.7	0.4	1.1	0.9	0.3	0.5	0.7	0.3	0.9	1.8	0.8
Nos. 40 to 42	M1 Mg	M1 Mg	18.1[b]	7.0[a]	10.5	7.9	4.2	5.9	7.4	2.5	3.1	8.7	8.0[b]	4.2
Nos. 43 to 45	56S Al	56S Al	0.3	1.0	0.2	0.3	0.2	0.05	−0.02	0.2	0.08	0.2	0.5	0.2
Nos. 46 to 48	2S Al	2S Al	<0.1	0.1	0.1	0.3	0.2	0.0	−0.1	0.1	−0.08	0.1	0.2	1.1

[a] No electrical contact from wire to spool. Wire broken on spool or at fastenings or both.
[b] Wire broken on spool or at fastenings or both.

TABLE II.—NET AVERAGE PER CENT WEIGHT LOSS FOR MAGNESIUM WIRES.

Couple			First Period			Second Period			Third Period			Fourth Period		
	Wire	Spool	New York	Kure Beach	State College	New York	Kure Beach	State College	New York	Kure Beach	State College	New York	Kure Beach	Stat College
Nos. 1 to 3	AZ31X Mg	AZ31X Mg	0	0	0	0	0	0	0	0	0	0	0	0
Nos. 4 to 6	AZ31X Mg	85-15 Brass	28.7	26.3	18.7	12.1	12.1	7.9	12.1	12.2	5.2	14.0	18.0	11.6
Nos. 7 to 9	AZ31X Mg	Zinc	16.4	12.4	9.3	6.0	5.6	3.4	5.2	5.4	2.4	6.7	8.7	5.2
Nos. 10 to 12	AZ31X Mg	M1 Mg	−9.7[a]	−2.2[a]	−4.4[a]	−2.7[a]	−1.3[a]	−3.0[a]	−3.0[a]	−3.0[a]	−1.0[a]	−2.2[a]	−2.6[a]	−1.3[a]
Nos. 13 to 15	AZ31X Mg	56S Al	12.8	4.6	7.0	5.6	2.2	2.3	4.1	1.4	1.0	6.0	4.5	3.0
Nos. 16 to 18	AZ31X Mg	2S Al	13.6	5.1	8.2	7.7	3.0	2.5	3.9	2.2	0.9	7.2	5.7	2.9
Nos. 25 to 27	M1 Mg	AZ31X Mg	7.6	3.0	5.3	3.5	1.4	2.1	3.2	0.4	1.8	2.7	0.3	3.1
Nos. 40 to 42	M1 Mg	M1 Mg	0	0	0	0	0	0	0	0	0	0	0	0

[a] "Negative loss" indicates galvanic protection of AZ31X Mg by M1 Mg.

were galvanically protected by magnesium. The results of most interest are those for AZ31X magnesium wire on the various spools. These are presented in bar graph form in Fig. 3.

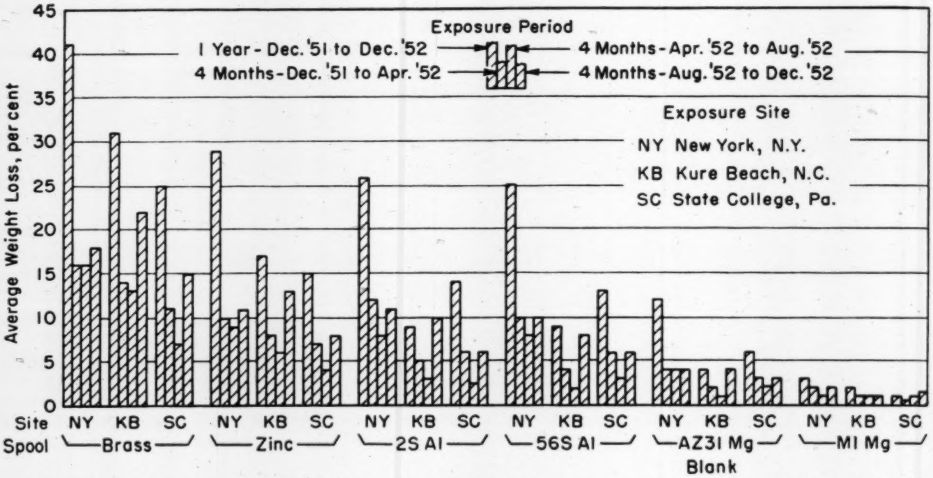
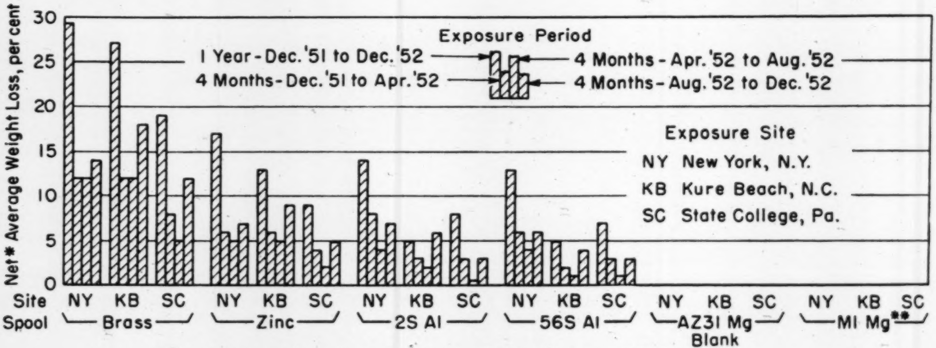


FIG. 3.—Average per cent Weight Loss of AZ31X Magnesium Wire Galvanically Coupled with Various Metal Spools.

Couples 1 to 3, AZ31X magnesium wire on AZ31X magnesium spool, constitute "blanks" for the data presented in Fig. 3. By subtracting these values from the corresponding total average weight losses, the net average losses are obtained, that is, the net losses due to galvanic action. These values are shown in Table II and are presented graphically in Fig. 4. Since M1 magnesium galvanically protects AZ31X magnesium, a "negative loss" is obtained. For clarity, this is shown as zero loss in Fig. 4.



* Total Loss Minus Loss for Blank (AZ31X Wire on AZ31X Spool).

** AZ31X Mg Wire on M1 Mg Spool is Galvanically Protected.

FIG. 4.—Net Average per cent Weight Loss of AZ31X Magnesium Wire due to Galvanic Coupling with Various Metal Spools.

Although fewer data for M1 magnesium wire were obtained, they have been included in Tables I and II. Both the total and net average losses are presented in Fig. 5.

It will be noted that no electrical contact existed between wire and spool on most of the couples with magnesium wire after exposure at New York and Kure Beach for 1 yr. Therefore, the weight loss figures may be assumed to be somewhat low for these couples. However, the relative corrosivity of the three sites, as indicated by the results for the shorter exposure periods, is reflected by the 1-yr exposure losses as well. Contact was maintained for all the 1-yr exposures for AZ31X magnesium wire on brass, and on all the 1-yr exposures at State College. Comparison of the "no contact" data with these points of reference suggests that the weight loss figures are of the correct order of magnitude.

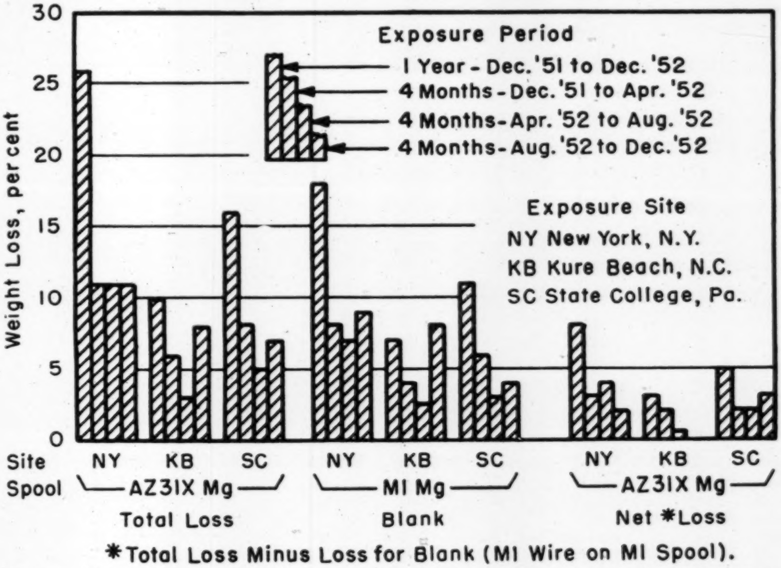


FIG. 5.—Total and Net Average per cent Weight Loss of M1 Magnesium Wire Galvanically Coupled with Magnesium Spools.

An inspection of Figs. 3 to 5 indicates that in general the cumulative corrosive effect of the three consecutive 4-month periods is greater than that obtained from a 1-yr continuous exposure. This may be due to an increase in the protective nature of the corrosion products with an increase in thickness of deposit. Samples exposed during the last third of the calendar year appear to be more affected than the sets exposed during the first and second 4-month periods. This is particularly noticeable at Kure Beach and at State College.

The AZ31X magnesium suffered the severest galvanic corrosion in contact with brass. Contact with zinc produced somewhat less corrosion, while contact with 2S and 56S was about equal and had the least effect. Industrial New York City atmosphere has a greater corrosive effect than either the marine atmosphere at Kure Beach (800-ft location) or the rural environment at State College.

Weight losses resulting from coupling AZ31X magnesium with more noble metal wires (couples included in this examination for completeness) were quite small. Except in cases where it is uncertain which metal of a couple will be anodic with respect to the other, it would be unnecessary to include the couple as anodic spool and cathodic wire.

The preliminary tests have shown the value of the new spool-wire couple in obtaining noticeable galvanic corrosion effects in relatively short exposure times. Additional work is indicated, however, in order better to establish the usefulness of this arrangement.

Respectfully submitted on behalf of the subcommittee,

GERALD KINGSLEY,
Chairman.

APPENDIX I

METHOD OF ASSEMBLY OF SPOOL-AND-WIRE TYPE GALVANIC COUPLE

Preparation of Spools:

1. Threaded lugs are inserted in the spools.
2. Brass machine screws are inserted in the lugs.
3. Spools are cleaned in 2 baths of petroleum ether.

NOTE.—Care must be taken at all times to retain knowledge of the identity of the spools and wires since it is impracticable to mark them in any permanent manner.

Preparation of Wires:

1. The required number of lengths of wire are cut to 38 in.
2. The wire is cleaned with a fine abrasive, such as Aloxite paper, and then swabbed with petroleum ether and cotton.
3. The wire is weighed to the nearest tenth of a milligram (line (*a*), Appendix IV).

NOTE.—Care must be taken in handling the wires to use cotton and wear clean gloves, in order to avoid getting perspiration and oil from the hands on the wire.

Assembly of Spool and Wire:

1. The spool is threaded into the winding machine, Fig. 1.
2. The wire is attached to one of the lugs by means of the screw.
3. The wire is wound by the machine, care being taken by the operator to maintain a slight tension on the wire as it is fed onto the spool.
4. The wire is fastened to the other lug and the excess cut off and weighed (line (*b*), Appendix IV).
5. The spool is inserted in its proper place on the rack.
6. The wire not in contact with the spool, the lugs, and the screws are painted with the varnish.

APPENDIX II

METHOD OF CLEANING SPOOL-AND-WIRE TYPE GALVANIC COUPLE

Determination of Cleaned End Weights:

1. The wires are unfastened at the lugs and the ends, the sections not in contact with the spool, are cut off.
2. Varnish is removed from the ends by soaking in hot toluene.
3. Ends are weighed (line (*d*), Appendix IV).

NOTE.—An average end weight, derived from end weights for the particular alloy where wire end corrosion did not occur, was used when wire ends were corroded or lost.

Determination of Exposed and Cleaned Wire Weights:

1. Wire is carefully removed from spool and cleaned by the appropriate method as listed below.
2. Cleaned wire is weighed (line (*f*), Appendix IV).

NOTE.—Care must be taken in removing magnesium wires so that pieces which tend to break off are not lost.

Cleaning Methods:[2]

Aluminum Alloys.—2 to 3 min in HNO_3 (sp gr 1.42) at room temperature. Loss due to cleaning: 2S Al, 0.03 per cent; 56S Al, 0.06 per cent.

Brass.—2 to 3 min in 1:1 HCl at room temperature. Loss due to cleaning: 0.03 per cent.

Magnesium Alloys.—20 per cent CrO_3 plus 1 per cent $AgNO_3$. 30 sec at 90 to 100 C. Losses due to cleaning: AZ31X Mg, 0.05 per cent; M1 Mg, 0.27 per cent.

Zinc.—(*a*) 5 min in 10 per cent NH_4Cl solution at 60 to 80 C. (*b*) 15 sec in 5 per cent CrO_3 plus 1 per cent $AgNO_3$ at boiling point. Loss due to cleaning: 0.11 per cent.

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[2] For reference purposes, see Tentative Method of Total Immersion Corrosion Test of Non-Ferrous Metals (B 185 – 43 T), 1952 Book of ASTM Standards, Part 2, p. 1045.

APPENDIX III

CHECK ANALYSES OF SPOOL AND WIRE MATERIALS

	Chemical Composition, per cent					
	Aluminum	Chromium	Copper	Magnesium	Manganese	Zinc
2S Aluminum:						
Nominal Composition	>99	...	...	...	...	...
Wire	>99.7	...	...	...	...	...
Spool	>98.9	...	0.10	0.05	...	<0.3
56S Aluminum:						
Nominal Composition	Balance	0.25	...	5.2	0.1	...
Wire	...	0.10	...	5.13	0.12	...
Spool	...	0.07	...	7.5	None	<0.3
85-15 Brass:						
Nominal Composition	...	...	85	...	...	15
Wire	...	...	84.67	...	...	15.23
Spool	...	...	84	...	...	16
M1 Magnesium:						
Nominal Composition	...	...	...	Balance	1.5	...
Wire	...	...	...	...	1.47	...
Spool	...	...	...	...	0.15	...
AZ31X Magnesium:						
Nominal Composition	3.0	...	...	Balance	0.3	1.0
Wire	3.20	...	...	...	0.46	0.90
Spool	5.0	...	...	...	0.35	1.3
Zinc:						
Nominal Composition	...	...	...	...	...	"Pure"
Wire	...	...	...	...	...	>99.97
Spool	...	...	...	...	...	>99.7

APPENDIX IV

GALVANIC COUPLE TEST

Wire—AZ31X Mg	Exposed—December 18, 1951
Spool—Brass	Removed—December, 1952
Location—State College	Period—First
Rack—1	

WEIGHT, IN GRAMS, OF WIRE AT VARIOUS STAGES DURING ASSEMBLY AND DISASSEMBLY

	Couple 4	Couple 5	Couple 6
(*a*) Gross weight	0.9998	1.0292	1.0284
(*b*) Excess weight	0.0617	0.0634	0.0657
(*c*) Weight of wire on spool $(a - b)$	0.9381	0.9658	0.9627
(*d*) Weight of protected ends	0.0534	0.0549	0.0525
(*e*) Weight of wire under test $(c - d)$	0.8847	0.9109	0.9102
(*f*) Weight of cleaned wire after exposure	0.6646	0.6881	0.6927
(*g*) Loss $(e - f)$	0.2201	0.2228	0.2175
(*h*) Loss, per cent $\left(\frac{g \times 100}{e}\right)$	24.9	24.5	24.0

NOTES.—Couple 4, wire broken once on each bolt; couples 5 and 6, good electrical contact to all wires.

Average loss, 24.5 per cent.

REPORT OF COMMITTEE B-4

ON

METALS FOR ELECTRICAL HEATING, ELECTRICAL RESISTANCE, AND ELECTRONIC APPLICATIONS*

Committee B-4 on Electrical Heating, Resistance, and Related Alloys held three meetings during the past year as follows: in Atlantic City, N. J., on June 24 and 25, 1953; in Washington, D. C., on October 8 and 9, 1953; and in New York City. on January 28 and 29, 1954.

The present membership of Committee B-4 totals 66 members, of whom 20 are classified as producers, 37 as consumers, and 9 as general interest members.

At the Washington meeting and through the cooperation of the National Bureau of Standards, Messrs. J. G. Reid and R. L. Henry gave a fine illustrated talk on "New Production Methods for Electronics."

Also during the Washington meeting a very interesting talk was given by Mr. E. S. Gulbransen of the Westinghouse Research Laboratories, on "Oxide Film on Nickel-Chromium Alloys."

Some consideration has been given to a two-meeting-a-year schedule instead of the three-meeting schedule now in effect, in the hope of encouraging interim meetings of the section groups and task forces whose meetings would augment the two meetings.

NEW TITLE AND SCOPE

The Board of Directors at its meeting on May 11 approved changes in title and scope of Committee B-4 as follows:

New Title.—Committee B-4 on Metallic Materials for Electrical Heating, Electrical Resistance, and Electronic Applications.

New Scope.—In general, Committee B-4 has jurisdiction over the classification, specification requirements, methods of test, questions of utility, and related subjects pertaining to wrought and cast metallic materials and parts for electronic and electrical resistance applications, for the structure and containers of electric furnaces, thermostatic metals and alloys, metallic materials for electronic devices and incandescent lamps, and materials for electrical contacts.

NEW TENTATIVES

The committee recommends that the following be accepted for publication as tentative as appended hereto:[1]

Tentative Specifications for:

Tungsten Wire Less Than 20 mils in Diameter,
Molybdenum Wire Less Than 20 mils in Diameter, and
Round Wire for Use as Electron Tube Grid Laterals and Verticles.

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[2]

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Electrical Heating Materials (C. L. Raynor, chairman) is working on a revision of the Method of Test for Change of Resistance with Temperature of Metallic Materials for Electrical Heating (B 70 – 39). Work has progressed to a point where five field laboratories are close to checking their results.

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13–18, 1954.

[1] The new tentatives were accepted by the Society and appear in the 1954 Supplement to Book of ASTM Standards, Part 2.

[2] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

Revisions are also in progress on the Standard Specifications for Drawn or Rolled Alloy, 80 per cent Nickel, 20 per cent Chromium, for Electrical-Heating Elements (B 82 – 52), and the Standard Specifications for Drawn or Rolled Alloy, 60 per cent Nickel, 16 per cent Chromium, and Balance Iron, for Electrical-Heating Elements (B 83 – 52). These revisions have to do with resistance changes with respect to temperatures.

It has also proposed to include in the Standard Method of Accelerated Life Test for Metallic Materials for Electrical Heating (B 76 – 39) a method of test for iron, chromium, and aluminum type alloys.

Subcommittee V on Wrought and Cast Alloys for High Temperature Use (E. Edmunds, chairman). — Consideration has been given to including nonmetallic resistors within the scope of this subcommittee.

High-temperature tests are in progress with the intent to include silicon carbide elements.

Tests are in progress on small heating elements having a base composition of 80 per cent nickel - 20 per cent chromium with respect to variants of carbon, manganese, and silicon. These tests are being conducted in neutralene produced gas at 2050 F. Initial results are promising.

This subcommittee continues work on creep tests.

Subcommittee VII on Thermostat Metals (P. H. Brace, chairman) is working on a revision of the Tentative Methods of Testing Thermostat Metals (B 106 – 51 T) and the Tentative Method of Test for Modulus of Elasticity of Thermostat Metals (Cantilever Beam Method) (B 223 – 51 T). There is continued work on testing for flexibility, hardness, and electrical properties for thermostat metals. A practical aim is to get good producer-consumer agreement.

Subcommittee VIII on Metallic Materials for Radio Tubes and Incandescent Lamps (S. A. Standing, chairman):

Section A on Nickel-Cathode Materials is drawing to completion its work on the revisions of the Tentative Methods of Testing Sleeves and Tubing for Radio Tube Cathodes (B 128 – 52 T) and Tentative Specification for Circular Cross-Section Nickel Cathode Sleeves for Electronic Devices (B 239 – 49 T).

The group on Physical Tests continues its work on disk cathode assemblies. Work is also in progress on collapse strength and measurement of camber with relation to cathodes.

The Gas Analysis group is doing work with regard to vacuum fusion analysis for small amounts of carbon and gas in small samples of nickel.

In the Chemical Analysis group, procedures have now been worked out with Committee E-3 on Chemical Analysis of Metals for determination of cobalt, copper, manganese, iron, titanium, and silicon. This group is now planning work on aluminum, magnesium, tungsten, and carbon.

The Cathode group, in connection with the National Bureau of Standards, is continuing its work for the evaluation of vacuum-melted nickel. Work is progressing on a standard triode and also on methods for interface impedence. Seven methods are under consideration in this project at the present time.

The Spectrographic Analysis group is following a program leading to improvements in procedures based upon the use of nickel oxide samples, which are being prepared and checked by the National Bureau of Standards. Heats of cathode nickel with a cobalt variable are still being worked upon.

Section C on Wire.—The group dealing with fine wire is in the process of revising tentative specifications on tungsten and other grid wires. They are also studying means of improving a test for "out of roundness."

Section F on Mica and Ceramics continues its general survey of the physical and mechanical properties of this material with respect to the needs of the electronic industry. This group also considers that some work in ceramics should be done with respect to "end use" applications, being mindful of the need for cooperative action with other committees, primarily Committee D-9 on Electrical Insulating Materials.

Section G on Clad and Plated Materials continues its work on proposed specifications for steel strip for radio tubes and incandescent lamp use. New limits on the thickness of cladding and plating materials were established. This group is considering the problems of limits on thickness, width and burrs, with better description of the physical properties of these materials.

Proposed revision to the Method of Test for Temper of Strip and Sheet Metals for Electronic Devices (Spring-Back Method) (B 155 - 50) is under consideration. Consideration is also being given to the problem of how best to orient studies of emission of plated cathodes.

Subcommittee IX on Method of Test for Alloys in Controlled Atmospheres (P. H. Brace, chairman).—The efforts of this committee are directed toward carburization research to meet the requirements of the steel heating industry which desires to raise the carburizing temperature to increase the rate of production. In this connection, test programs are being set up.

Subcommittee X on Contact Materials (J. D. Kleis, chairman).—Since the time of the last annual report, Mr. Kleis has been asked to assume the chairmanship upon the retirement of F. E. Carter, who was chairman for many years.

Mr. E. I. Shobert, II, of the subcommittee, received the ASTM Award of Merit at the 1953 Annual Meeting.

Work of this committee has continued with its study of the surety of making a circuit test with gold, fine silver, copper, and tungsten contacts. Further controls have been established with regard to preoxidation cleaning.

An interesting talk was given at the fall meeting by Mr. V. J. Albano of the Bell Telephone Laboratories on "Films on Metals."

Work continues on a test method to be used to determine the thermal conductivity of contact materials. Work also continues on standardization of contact forms and sizes.

The section on Microcontacts is now organized and is establishing its work load with respect to test devices and test methods.

An interesting talk on "Microcontacts" was given by R. Holm. This dealt with many of the difficulties involved with surface films at low contact forces.

The report has been submitted to letter ballot of the committee, which consists of 66 members; 47 members returned their ballots, of whom 40 voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

S. A. STANDING,
Chairman.

STANTON UMBREIT,
Secretary,

REPORT OF COMMITTEE B-5

ON

COPPER AND COPPER ALLOYS, CAST AND WROUGHT*

Committee B-5 on Copper and Copper Alloys, Cast and Wrought, held two meetings during the year: at Philadelphia, Pa., on October 7, 1953, and at Washington, D. C., on February 4, 1954. At these two sessions the Advisory Committee and Subcommittees W-1, W-2, W-3, W-4, F-1, and G-1 also met; Subcommittee G-3 met at the October sessions.

During the year, 10 members were added to the committee and there were 8 removals. At the present time the committee consists of 137 members, of whom 112 are voting members; 50 are classified as producers, 42 as consumers, and 20 as general interest members.

At the February meeting the election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, G. H. Harnden.

First Vice-Chairman, W. D. France.

Second Vice-Chairman, William Romanoff.

Secretary, V. P. Weaver.

RECOMMENDATIONS ACCEPTED BY THE ADMINISTRATIVE COMMITTEE ON STANDARDS

Subsequent to the 1953 Annual Meeting, Committee B-5 presented to the Society through the Administrative Committee on Standards the following recommendations:

Tentative Specification for:

Copper and Copper-Alloy Die Forgings (Hot Pressed) (B 283 - 53 T).

Revision of Tentative Specifications for:

General Requirements for Wrought Copper and Copper-Alloy Rod, Bar, and Shapes (B 249 - 52 T), and

General Requirements for Wrought Seamless Copper and Copper-Alloy Pipe and Tube (B 251 - 52 T).

Tentative Revision of Standard Specifications for:

Copper Plates for Locomotive Fireboxes (B 11 - 49),

Copper Rods for Locomotive Staybolts (B 12 - 52),

Seamless Copper Water Tube (B 88 - 51),

Seamless Brass Tube (B 135 - 52),

Manganese Bronze Rod, Bar, and Shapes (B 138 - 52), and

Copper-Alloy Condenser Tube Plates (B 171 - 52).

These recommendations were accepted by the Administrative Committee on Standards on September 9, 1953, and the new and revised tentative specifications and tentative revisions appear in the 1953 Supplement to the Book of ASTM Standards, Part 2.

RECOMMENDATIONS AFFECTING STANDARDS

The committee is submitting 2 new tentative specifications, revisions in 3 tentative specifications, revisions in 19 standard specifications for immediate adoption, the adoption of 3 tentatives as standard, and the adoption of 14 tentative revisions as standard. The standards and tentatives affected, together with the revisions recommended, are covered in detail in Appendix I.[1]

The recommendations in this report

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13–18, 1954.

[1] See p. 167.

have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[2]

ACTIVITIES OF THE ADVISORY COMMITTEE

Recommendations for revisions in the regulations governing the committee were approved by letter ballot of the committee. A task group (L. H. Adam, chairman) prepared these recommendations, among which are: (*a*) the term "copper-base alloy ingot" for "copper ingot" in the Scope of the Committee, (*b*) the term "Executive Subcommittee" for "Advisory Committee," (*c*) more definite statements on the functions of the Executive Subcommittee, (*d*) approval of establishment of Technical Subcommittees and groupings thereof and of the appointment of Technical Subcommittee chairmen by the Main Committee instead of the Executive Subcommittee.

A paper entitled "The Mechanical Properties of Some Nickel Silver Alloy Strips," by G. R. Gohn, J. P. Guerard, and G. J. Herbert of Bell Telephone Laboratories Inc., was presented at the February meeting of the committee and is appended hereto.[3]

ACTIVITIES OF SUBCOMMITTEES

The following is the report of the several subcommittees during the year. The actions on standards are given in detail in the Appendix.[1]

Subcommittee W-1 on Plate, Sheet, and Strip (W. D. France, chairman) recommended that revisions be incorporated in Tentative Specification B 122. Revisions for immediate adoption were recommended in Standard Specifications B 96, B 97, B 100, and B 152. Specification B 19 was recommended for adoption as standard without revision. Adoption as standard was recommended for tentative revisions of five standard specifications: B 11, B 130, B 131, B 152, and B 171. The subcommittee recommends a proposed new Tentative Specification for Copper-Zinc-Manganese Alloy (Manganese Brass) Sheet and Strip prepared by a task group (M. M. Randle, chairman).

A task group (E. W. Lovering, chairman) prepared the requirements for a new 10 per cent nickel silver alloy for Specification B 122. A task group (V. P. Weaver, chairman) prepared the revisions for chemical requirements in Specifications B 96, B 97, and B 100. A task group (G. H. Harnden, chairman) prepared the revision on availability of hard temper in Specification B 152.

Among the subjects being considered by the subcommittee are the preparation of requirements for tin-coated copper, more definite requirements for edge finish, the revision of Basis of Purchase sections, the revision of Specification B 171 with respect to lot size and flatness tolerances, the revision of Specification B 100 to define limits in plate size, and recognition of direction of rolling in the selection of tensile specimens.

Subcommittee W-2 on Rods, Bars, and Shapes (J. D. MacQueen, chairman) recommended that revisions be incorporated in Tentative Specification B 133. Revisions for immediate adoption were recommended in Standard Specifications B 98, B 124, B 138, B 140, B 150, and B 187. Adoption as standard was recommended for tentative revisions of four standard specifications: B 12, B 21, B 138, and B 150.

A task group (G. H. Harnden, chairman) prepared the revisions for tensile requirements in Specification B 133. A task group (V. P. Weaver, chairman) prepared the revisions for chemical requirements of copper-silicon alloys in Specifications B 98 and B 124. A task group (G. C. Mutch, chairman) prepared the revision for manganese limit in Specification B 138. A task group (V. P. Weaver, chairman) prepared the revisions in lead limit and elongation for Specification B 140. A task group (J. F. Klement, chairman) prepared chemical and tensile requirements for a new alloy No. 3 in Specification B 150.

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[2] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

[3] See p. 229.

Among the subjects being considered by the subcommittee are the deletion of provision for machined bend test specimens in Specification B 187; the revision of chemical requirements for rod of type OF copper; consideration of alloys with lower nickel content for Specification B 151; revision of the copper limits for alloy No. 2, and the list of alloys in Specification B 124; and in Specification B 139, the clarification of requirements for test specimens.

Subcommittee W-3 on Wire and Wire Rod (Sidney Metzger, chairman) recommended revisions for immediate adoption in Specifications B 99, B 159, and B 206. The subcommittee also recommended that Specifications B 250 and B 272 be retained as tentative.

A task group (V. P. Weaver, chairman) prepared the revisions in chemical requirements for Specification B 99. A task group (M. D. Helfrick, chairman) prepared requirements to provide for wire under 0.020 in. diameter in Specification B 159. A task group (E. W. Lovering, chairman) prepared requirements for a new 12 per cent nickel silver for Specification B 206.

Among the subjects under consideration in the subcommittee are the preparation of requirements for wire other than round in Specification B 159, and flat copper products with finished edges in sizes wider than provided for in Specification B 272.

Subcommittee W-4 on Pipe and Tube (G. C. Mutch, chairman) recommended that revisions be incorporated in Tentative Specification B 251. Revisions for immediate adoption were recommended in Standard Specifications B 42, B 68, B 75, B 88, and B 188. Adoption as standard was recommended for tentative revisions of five standard specifications: B 14, B 43, B 88, B 111, and B 135.

A task group (J. E. McGraw, chairman) prepared for Specification B 251 straightness tolerances for short-length, rectangular, and square tube, and revisions in lot size for pipe. A task group (G. C. Mutch, chairman) recommended a minimum phosphorus content for type DPA copper in Specification B 75 and elimination of the microscopic examination for cuprous oxide in type DHP copper in Specifications B 42, B 68, B 75, and B 88.

Among the subjects under consideration in the subcommittee are the review of temper requirements in Specification B 75 and requirements for Rockwell hardness in tube specifications; for B 111, the revision of requirements for the expanding test, dimensional tolerances, and finish; preparation of yield strength requirements for the following specifications when used in the Boiler and Pressure Vessel Code of the American Society of Mechanical Engineers: B 13, B 42, B 43, B 75, and B 111; revision of chemical requirements for type OF copper in Specification B 75; and preparation of a new specification for copper tube in "Type B" sizes.

Subcommittee F-1 on Castings, and Ingots for Remelting (G. H. Clamer, chairman; M. L. Steinbuch, secretary) recommended revisions for immediate adoption in Standard Specification B 30. Recommended Practice B 208 and Specification B 271 were recommended for adoption as standard without revision. The subcommittee recommends a proposed new Tentative Specification for

Nickel-Tin Bronze Castings prepared by a task group (J. S. Vanick, chairman).

Among the subjects under consideration in the subcommittee are the revision of chemical requirements in Specification B 198, the review of chemical compositions for the proper number of significant figures, and the assembling of data on high-temperature properties of cast copper-base alloys for the Manufacturers' Standardization Society of the Valve and Fittings Industry and other groups.

Subcommittee G-1 on Methods of Test (G. R. Gohn, chairman; J. P. Guerard, secretary) is preparing a series of revisions in the dimensional tolerance requirements as now set forth in the various wrought product specifications. These revisions, which include, in the case of dispute or referee test, the choice of instrument for determining various dimensions, are based on studies of the problem over a period of several years.

The subcommittee is continuing its review of previous studies on the determination of grain size. The report of the task group on grain size determination is appended hereto.[4]

The subcommittee is also studying the implications in the following two papers that appeared in the ASTM BULLETIN (October, 1953):

"Correlation of Published Data for Correction of Rockwell Diamond Penetrator Hardness Tests on Cylindrical Specimens," by R. S. Sutton and R. H. Heyer.

"Survey of Investigations of Effect of Specimen Thickness on Rockwell Tests," by R. H. Heyer and V. E. Lysaght.

The latter paper includes work initiated by the subcommittee several years ago to clarify the hardness testing of wrought copper and copper alloys.

Subcommittee G-2 on Tolerances (J. E. McGraw, chairman), in cooperation with Subcommittee W-4, recommended for Specification B 251 straightness tolerances for rectangular and square tube, straightness tolerances for short-length tube, and revisions in lot size for pipe.

Subcommittee G-3 on Editorial and Publications (W. F. Roeser, chairman) recommended a proposed new Tentative Classification of Wrought Copper-Base Alloys.

In cooperation with Subcommittee F-1 and the "W" subcommittees, the specifications under the jurisdiction of these subcommittees are being reviewed for editorial consistency.

This report has been submitted to letter ballot of the committee, which consists of 112 voting members; 88 members returned their ballots, of whom 84 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

G. H. HARNDEN,
Chairman.

V. P. WEAVER,
Secretary.

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[4] See p. 173.

APPENDIX I

RECOMMENDATIONS AFFECTING STANDARDS FOR COPPER AND COPPER ALLOYS, CAST AND WROUGHT

In this Appendix are given the recommendations affecting certain standards covering copper and copper alloys which are referred to earlier in this report. The standards appear in their present form in the 1952 Book of ASTM Standards, Part 2, or in the 1953 Supplement to the Book of ASTM Standards, Part 2.

NEW TENTATIVES

The committee recommends the following two new specifications for publication as tentative:

Tentative Specification for Copper-Zinc-Manganese Alloy (Manganese Brass) Sheet and Strip,[1] and

Tentative Specification for Nickel-Tin Bronze Castings.[1]

REVISIONS OF TENTATIVES

The committee recommends that the following three tentative specifications be revised as indicated below and continued as tentative.

Tentative Specification for Copper-Nickel-Zinc Alloy (Nickel Silver), and Copper-Nickel Alloy Plate, Sheet, Strip, and Rolled Bar (B 122 - 52 T):

Table I.—Add alloy No. 9 (70 Cu, 10 Ni, 20 Zn) with chemical requirements as follows:

Copper, per cent	69.0 to 73.5
Nickel, per cent	9.0 to 11.0
Lead, max, per cent	0.10
Iron, max, per cent	0.25
Manganese, max, per cent	0.50
Zinc	remainder

TABLE I.—TENSILE AND ROCKWELL VALUES FOR ALLOY NO. 9

Temper	Tensile Strength, psi		Approximate Rockwell Hardness B Scale	
	Min	Max	Min	Max
Quarter hard	55 000	70 000	60	80
Half hard	63 000	77 000	70	85
Hard	73 000	87 000	79	91
Extra hard	79 000	91 000	83	93

Table II.—Add alloy No. 9 with tensile and Rockwell values as shown in the accompanying Table I.

Section 8.—Indicate that all grain size values apply to alloy No. 9.

Table III.—Add approximate Rockwell hardnesses for alloy No. 9 as follows:

Temper, Nominal Grain Size	Approximate Rockwell Hardness, B Scale	
	Min	Max
0.070-mm	5	20
0.035-mm	20	40
0.015-mm	35	55

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[1] The new tentative was accepted by the Society and appears in the 1954 Supplement to Book of ASTM Standards, Part 2.

Tentative Specification for Copper Rod, Bar, and Shapes (B 133 – 52 T):

Table I.—For hard-temper bars, combine the first two size groups to read "Over 0.188 to ⅜, incl" with a minimum tensile strength requirement of 42,000 psi and a minimum elongation requirement of 12 per cent.

Tentative Specification for General Requirements for Wrought Seamless Copper and Copper-Alloy Pipe and Tube (B 251 – 53 T):

Section 4(a).—Revise "Lot Size" to read as follows:

> *Lot Size.*—For tube, the lot size shall be 5000 lb or fraction thereof. For pipe, the lot size applicable to ASTM Designations B 42 and B 43 shall be as follows:

Nominal Pipe Size, in.	Lot Weight, lb
Up to 1½, incl	5 000 or fraction thereof
Over 1½ to 4, incl	10 000 or fraction thereof
Over 4	40 000 or fraction thereof

Section 8(j).—Revise to read as follows:

> **(j) Straightness Tolerances:**
>
> (*1*) *Round Tubes.*—For round tubes of any drawn temper, ¼ to 3½ in. in outside diameter, inclusive, but not copper water tube, pipe, redraw tube, extruded tube, or any annealed tube, the straightness tolerances applicable to ASTM Designations B 75, B 135, and B 188 shall be in accordance with Table XII.
>
> (*2*) *Rectangular and Square Tubes.*—For rectangular and square tubes of any drawn temper, the straightness tolerance applicable to ASTM Designation B 188 shall be ½-in. maximum curvature (depth of arc) in any 6-ft portion of the total length.

New Table.—Add a new Table XII to read as shown in the accompanying Table II.

ADOPTION OF TENTATIVES AS STANDARD

The committee recommends that the following three tentatives be approved for reference to letter ballot of the Society for adoption as standard without revision:

Tentative Specifications for:

Cartridge Brass Sheet, Strip, Plate, Bar, and Disks (B 19 – 52 T), and

Copper-Base Alloy Centrifugal Castings (B 271 – 52 T).

Tentative Recommended Practice for Tension Test Specimens for Copper-Base Alloys for Sand Castings (B 208 – 49 T).

REVISION OF STANDARDS, IMMEDIATE ADOPTION

The committee recommends for immediate adoption revisions in 19 specifications as indicated below and accordingly asks for a nine-tenths affirmative vote at the Annual Meeting in order that these modifications may be referred to letter ballot of the Society.

TABLE II.—STRAIGHTNESS TOLERANCES FOR COPPER AND COPPER-ALLOY TUBE[a] IN ANY DRAWN TEMPER.

(Applicable to ASTM Designations B 75, B 135, and B 188)

NOTE.—Applies to round tube in any drawn temper from ¼ to 3½ in. in outside diameter, inclusive.

Length, ft[b]	Maximum Curvature (Depth of Arc), in.
Over 3 to 6, incl	3/16
Over 6 to 8, incl	5/16
Over 8 to 10, incl	½

[a] Not applicable to copper water tube, pipe, redraw tube, extruded tube, or any annealed tube.

[b] For lengths greater than 10 ft, the maximum curvature shall not exceed ½ in. in any 10-ft portion of the total length.

Standard Specification for Copper-Base Alloys in Ingot Form for Sand Castings (B 30 – 49):

Section 5.—Add Paragraph (*d*) to read: "In those cases where the method of sampling is not covered by the preceding Paragraphs (*a*) to (*c*), inclusive, the procedure shall be agreed upon between the manufacturer and the purchaser.

Standard Specification for Seamless Copper Pipe, Standard Sizes (B 42 – 52):

Section 8.—Add a second sentence to read: "When DHP copper is supplied, microscopic examination for cuprous oxide is not required."

Standard Specification for Seamless Copper Tube, Bright Annealed (B 68 – 51):

Section 8.—Revise to read: "Samples of types DLP and OF copper shall be free of cuprous oxide as determined by microscopic examination at a 75× magnification. When DHP copper is supplied, microscopic examination for cuprous oxide is not required."

Standard Specification for Seamless Copper Tube (B 75 – 52):

Table I.—For type DPA copper, add a minimum phosphorus limit of 0.015 per cent.

Section 10.—Revise to read: "Samples of types DLP and OF copper shall be free from cuprous oxide as determined by microscopic examination at a 75× magnification. When DHP or DPA copper is supplied, microscopic examination for cuprous oxide is not required."

Standard Specification for Seamless Copper Water Tube (B 88 – 51):

Section 5.—Add a second sentence to read: "When DHP copper is supplied, microscopic examination for cuprous oxide is not required."

Standard Specification for Copper-Silicon Alloy Plate and Sheet for Pressure Vessels (B 96 – 51):

Table I.—For alloy A, delete the maximum allowance for tin. For alloy C, delete the maximum allowances for manganese and zinc.

Appendix.—In Table III delete alloys A-3, C-22, C-23, and C-24.

Standard Specification for Copper-Silicon Alloy Plate, Sheet, Strip, and Rolled Bar for General Purposes (B 97 – 51):

Table I.—For alloy A, delete the maximum allowance for tin. For alloy B, delete the maximum allowance for zinc. For alloy C, delete the maximum allowances for manganese and zinc.

Appendix.—In Table III delete alloys A-3, B-11, B-13, B-15, C-22, C-23, and C-24.

Standard Specification for Copper-Silicon Alloy Rod, Bar, and Shapes (B 98 – 52):

Table I.—For alloy A, delete the maximum allowances for tin and zinc. For alloy D, delete the maximum allowance for zinc. Delete Alloy C and references to it in Table II and Section 7.

Appendix.—In Table III delete alloys A-3, A-4, B-11, B-15, C-22, C-23, C-24, and D-31.

Standard Specification for Copper-Silicon Alloy Wire for General Purposes (B 99 – 51):

Table I.—Delete the maximum allowances for tin for alloys A and B. For alloy A, delete the maximum allowance for zinc. Delete alloy C and references to it in Table II and Section 7.

Appendix.—In Table III delete alloys A-3, A-4, B-11, B-15, C-22, C-23, and C-24.

Standard Specification for Rolled Copper-Alloy Bearing and Expansion Plates and Sheets for Bridge and Other Structural Uses (B 100 – 52):

Section 4.—For alloy No. 2, delete the maximum allowance for tin.

Standard Specification for Copper and Copper-Base Alloy Forging Rod, Bar, and Shapes (B 124 – 52):

Table I.—For alloys Nos. 7 and 8, delete the reference to footnote *a* for tin. For alloy No. 9, delete the reference to footnote *a* for tin, manganese, and zinc.

Table II.—For alloy No. 4, revise manganese limit "0.50 max" to read "0.05 to 0.5" per cent. For alloys 7 and 8, delete maximum allowance for tin. For alloy 9, delete the maximum allowances for tin, manganese, and zinc.

Standard Specification for Manganese Bronze Rod, Bar, and Shapes (B 138 – 52):

Table I.—For alloy A, revise manganese limit "0.5 max" to read "0.05 to 0.5" per cent.

Standard Specification for Leaded Red Brass (Hardware Bronze) Rod, Bar, and Shapes (B 140 – 52):

Table I.—For alloy B, change the present upper lead limit of "2.2" to read "2.5" per cent.

Table II.—For half-hard rounds, hexagons, and octagons ½ in. and under in diameter or thickness, revise the present minimum elongation value of "10" to read "7" per cent.

Standard Specification for Aluminum Bronze Rod, Bar, and Shapes (B 150 – 52):

Table I.—Add a new alloy No. 3 with chemical requirements as follows:

Copper, per cent	88.0 to 92.5
Aluminum, per cent	6.0 to 8.0
Iron, per cent	1.5 to 3.5
Sum of named elements, min, per cent	99.5

TABLE III.—TENSILE REQUIREMENTS FOR ALLOY NO. 3.

Diameter or Thickness, in.	Tensile Strength, min, psi	Yield Strength, min, psi	Elongation in 4× Diameter or Thickness of Specimen, min, per cent
Rods and Bars:			
½ and under	80 000	40 000	30
Over ½ to 1, incl	75 000	35 000	30
Over 1 to 2 incl	70 000	32 000	30

TABLE IV.—RADIUS FOR SQUARE CORNERS

Specified Thickness, in.	Maximum Radius of Corners Allowable for Square Corners, in.
1/32 to 1/16, incl	1/100
Over 1/16 to 3/16 (0.188), incl	1/64
Over 3/16 (0.188) to 1, incl	1/32
Over 1	1/16

Table II.—Add tensile requirements for alloy No. 3 as shown in the accompanying Table III.

Standard Specification for Copper Sheet, Strip, Plate, and Rolled Bar (B 152 – 52):

Section 5(a).—Indicate that footnote *a* also applies to hard temper.

Standard Specification for Phosphor Bronze Wire (B 159 – 52):

Section 1.—Revise size ranges to

TABLE V.—RADIUS FOR ROUNDED CORNERS.

Specified Thickness, in.	Nominal Radius of Corners, in.	
	For Widths up to and Including 2× Thickness	For Widths More Than 2× Thickness
Up to 0.072, incl.	0.012	Full rounded edges as given in Section 14 (*e*)
Over 0.072 to 1/8, incl.	1/64	Full rounded edges as given in Section 14 (*e*)
Over 1/8 to 3/16 (0.188), incl.	1/32	1/32
Over 3/16 (0.188) to 1, incl.	1/16	1/16
Over 1	1/8	1/8

TABLE VI.—RADIUS FOR ROUNDED EDGE.

Specified Thickness, in.	Nominal Radius of Rounded Edge, in.	Tolerance on Radius, plus and minus, in.
Up to 3/16 (0.188), incl.	1 1/4 × thickness	1/2 × thickness
Over 3/16 (0.188)	1 1/4 × thickness	1/4 × thickness

read as follows, retaining the present footnote 3.

	Size of Wire, in.
Alloy A[3]	Up to 0.500
Alloys C and D	Up to 0.250

Standard Specification for Copper Bus Bar, Rod, and Shapes (B 187 – 52):

Section 14.—Revise Paragraphs (*b*), (*c*), and (*d*) to read as follows:

(*b*) *Square Corners.*—Unless otherwise specified, bar shall be finished with commercially square corners with the maximum permissible radius shown in Table VIII (accompanying Table IV).

(*c*) *Rounded Corners.*—When specified, bar may be finished with corners rounded as shown in Fig. 1 to a quarter circle with a radius as shown in Table IX (accompanying Table V). The tolerance on the radius shall be ±25 per cent.

(*d*) *Rounded Edge.*—When specified, bar may be finished with edges rounded as shown in Fig. 2, with a radius of curvature as shown in Table X (accompanying Table VI).

Standard Specification for Seamless Copper Bus Pipe and Tube (B 188 – 52):

Section 2.—Add at the end of the section: ". . . ., except sampling procedure, which shall be in accordance with Section 8."

New Section.—Add a new Section 8 to read as follows, renumbering subsequent sections accordingly:

8. *Number of Test Specimens.* (*a*) Specimens shall be selected for test purposes from each lot of 5000 lb or fraction thereof, of each size and form, according to the following schedule:

Number of Pieces in Lot	Number of Specimens to be Taken[a]
1 to 50	1
51 to 200	2
201 to 1500	3
Over 1500	0.2 per cent of total number of pieces in the lot

[a] Each specimen shall be taken from a separate piece.

(*b*) Specimens selected in accordance with Paragraph (*a*) shall be subjected to the Rockwell hardness test and to the electrical resistivity or conductivity test to determine conformance to the requirements prescribed in Table I.

(*c*) One specimen shall be tested for tensile properties and one for bending, if required, to determine conformance to the requirements in Table I.

(*d*) In the case of coppers designated as oxygen-free or deoxidized, a section of each specimen selected in accordance with Paragraph (*a*) shall be submitted to microscopic examination as specified in Section 5, and also to the embrittlement test, if specified, as prescribed in Section 6.

Standard Specification for Copper-Nickel-Zinc Alloy (Nickel Silver) Wire (B 206 – 52):

Section 1.—In Paragraph (*a*), second sentence, revise "four" to read "five" and add alloy D with nominal composition 65 per cent copper, 12 per cent nickel, 23 per cent zinc. In Paragraph (*b*) add "*Alloy D.*—For general use."

Table I.—Add chemical requirements for alloy D as follows:

Copper, per cent	63.5 to 66.5
Nickel, per cent	11.0 to 13.0
Lead, max, per cent	0.05
Iron, max, per cent	0.25
Manganese, max, per cent	0.50
Zinc	remainder

Table II.—Add tensile requirements for alloy D as follows:

Temper	Tensile Strength, psi
Quarter hard	73 000 to 88 000
Half hard	88 000 to 103 000
Hard	108 000 to 123 000
Spring:	
0.020 to 0.0253, incl	130 000 min
Over 0.0253 to 0.0625, incl	125 000 min
Over 0.0625 to 0.125, incl	120 000 min
Over 0.125 to 0.250, incl	112 000 min

Table III.—In the first column add "Alloy D" for all grain sizes.

ADOPTION OF TENTATIVE REVISIONS OF STANDARDS AS STANDARD

The committee recommends the adoption as standard of the tentative revisions issued in 1952 for the Standard Specification for Copper and Copper-Alloy Seamless Condenser Tubes and Ferrule Stock (B 111 – 52), and in 1953 for the following 14 standard specifications:

Standard Specifications for:

Copper Plates for Locomotive Fireboxes (B 11 – 49),
Copper Rods for Locomotive Staybolts (B 12 – 52),
Seamless Brass Boiler Tubes (B 14 – 49),
Naval Brass Rod, Bar, and Shapes (B 21 – 52),
Seamless Red Brass Pipe, Standard Sizes (B 43 – 52),
Seamless Copper Water Tube (B 88 – 51),
Copper and Copper-Alloy Seamless Condenser Tubes and Ferrule Stock (B 111 – 52),
Gilding Metal Strip (B 130 – 52),
Gilding Metal Bullet Jacket Cups (B 131 – 51),
Seamless Brass Tube (B 135 – 52),
Manganese Bronze Rod, Bar, and Shapes (B 138 – 52),
Aluminum Bronze Rod, Bar, and Shapes (B 150 – 52),
Copper Sheet, Strip, Plate, and Rolled Bar (B 152 – 52), and
Copper-Alloy Condenser Tube Plates (B 171 – 52).

APPENDIX II

REPORT ON DETERMINATION OF GRAIN SIZE[1]

Early in 1940 the Frankford Arsenal representatives on Committee B-5 pointed out the inadequacy of the present methods for grain size determination on brass. This was particularly critical on cartridge case cups. Frequently there were wide discrepancies in the grain size readings as determined by the Arsenal and the manufacturers on identically the same material. This could be due to the fact that in many cases the range of grain size encountered in cartridge brass cups was frequently much wider than provided for in the original grain size chart in ASTM Method E 2 - 39 T.[2] This led to the practice of approximating the grain size, particularly in the abnormal zones of the cartridge cup.

It appeared, therefore, that before coordination could be reached on the specifications for cartridge cups it would be necessary to make a thorough review of the several methods currently used for determination of grain size of brass. A special committee on Grain Size Determination of Subcommittee G-1, Committee B-5, was appointed. A round-robin testing program was developed with nine different laboratories participating. Test specimens were prepared and furnished by the Frankford Arsenal, as was a suggested procedure for making the grain size determinations. As the results were reported, they were statistically analyzed and consolidated by at least three statisticians. (See Appendices B, C, D, and E, taken directly from the reports of the statisticians.)

During the course of the investigation, the scope was broadened to include grain size determination on cartridge brass flat products. However, the results of this investigation would well apply generally to copper and all single-phase wrought copper alloys in all forms.

The report of the original 1940 committee was found to provide sound basic data, including both original observations and statistical analysis, which have enabled the 1953 Task Group to develop its report. Although many of the original conclusions have been substantiated during the elapsed 13 years, the current Task Group has found it advisable to modify the original recommendations and to submit new recommendations based on latest metallographic practice on grain size determination of copper and copper-base alloys.

In this report the conclusions and recommendations of the 1940 special committee are described. These are followed by the 1953 group's recommendations. The history of the 1940 grain size investigations, as well as the statistical data referred to earlier, have been included as Appendices A to E.

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[1] This report was made by the 1953 Task Group on Determination of Grain Size, organized under Subcommittee G-1 on Methods of Test. The membership of the Task Group included the following: G. H. Harnden, *Chairman*, H. C. Ashley, W. D. France, N. H. Murdza, R. S. Pratt, and V. P. Weaver.

[2] Tentative Methods of Preparation of Micrographs of Metals and Alloys (E 2 - 39 T), 1939 Book of ASTM Standards, Part I, p. 1214.

CONCLUSIONS OF THE 1940 COMMITTEE

The following constitute the conclusions of the original 1940 Special Committee on Grain Size Determination of Subcommittee I, Committee B-5; they were based on the statistical report of that group.

Jeffries' Planimetric Method:

Because of the small number of laboratories participating in this test, it was difficult to form definite conclusions. Based on the test information returned, the following procedure is recommended when the Jeffries' method of determining grain size is used:

1. A magnification of 75 × is recommended for grain sizes 0.045 to 0.200 mm.
2. A magnification of 37.5 × is recommended for grain sizes larger than 0.200 mm. (On the basis of the data the committee should recommend 25 ×, but this is an odd size, being one third of 75 ×, the basic magnification.)
3. A magnification of 300 × is recommended for grain sizes smaller than 0.045 mm. (A magnification of 75 × is not sufficiently large for accurate measurements by Jeffries' Count. The data are not conclusive on either 150 × or 250 ×, although results obtained by the two indicate approximately the same degree of accuracy. The magnification of 250 × appears preferable, and therefore a magnification of 300 × is recommended to accommodate the standard ranges of the instruments available.)

Heyn's Intercept Method:

Results of statistical analysis indicated that it was impossible to obtain comparable results between laboratories within the desirable range of variability by the use of the intercept method.

Comparison Method Using Transparencies:

Although the number of laboratories submitting results by this method was small, the agreement between operators in the same laboratory was good, and the agreement between laboratories was also good.

Comparison Method Using Opaque Prints:

1. Reproducibility of observations by single operators was noticeably better than between operators in an individual laboratory.
2. Analysis indicated that the greatest contribution to the over-all variability was the variability between laboratories. It also indicated that there existed a definite bias. (Some laboratories tend consistently to read low and others tend consistently to read high.) This difference between laboratories was not so great between 0.100 and 0.200 mm as on the smaller grain sizes.
3. The bias might be improved or completely removed by adhering to the following suggestions:
   (*a*) Since the bias appeared to be less on the larger grain sizes, a higher magnification should be used on the smaller grain sizes.
   (*b*) More frequent checking of the operators against a quantitative method should be made.
   (*c*) Magnifications should be checked at regular intervals of not less than once per week against a stage micrometer.
4. The same changes in magnification were recommended as were recommended for the Jeffries' method.
5. By increasing the magnification to 300 × on sizes under 0.045 mm, the usable range of the ASTM charts would be increased to 0.0025 mm. If magnification could not be increased, a new chart for 0.005 mm was recommended for addition to the ASTM series.

6. Decreasing the magnification to 37.5 × increases the range of the present ASTM charts to 0.400 mm. The committee recommended the addition of a new chart for 0.300 mm to the present ASTM charts. Larger grain sizes should be compared at a magnification of 18.75 ×.

RECOMMENDATIONS OF THE 1940 COMMITTEE

The following recommendations were made:

1. The intercept method is not satisfactory and is, therefore, not recommended for use.

2. The transparency method gives more consistent results than the comparison method, is less time-consuming than the quantitative Jeffries' method, and is the least fatiguing of the three methods under consideration.

3. It is recommended that:

(*a*) Transparency method be adopted as the standard procedure for the determination of grain size of wrought copper alloys.

(*b*) Jeffries' method be considered as the referee method in case of controversy since it is the only acceptable quantitative method, even though its range of reproducibility is no smaller than that of the qualitative methods.

(*c*) Grain size be determined in accordance with the following magnifications:

Actual Grain Size Range, mm	Magnification
Below 0.045	300 ×
0.045–0.200	75 ×
Over 0.200–0.600	37.5 ×
Over 0.600	18.75 ×

(*d*) Two new photomicrographs be added to plate No. 3 of ASTM Method E 2 – 39 T, as follows:

1. 0.020 mm.
2. 0.300 mm.

These, with the magnifications recommended in the above paragraph (*c*), will give the following grain size standards:

Chart Value[a]	Magnification			
	300 ×	75 ×	37.5 ×	18.75 ×
0.010(a)	0.002			
0.015(b)				
0.020(n)	0.005			
0.025(c)				
0.035(d)	0.009			
0.045(e)	0.011	0.045		
0.065(f)	0.016	0.065		
0.090(g)	0.022	0.090		
0.120(h)	0.030	0.120		
0.150(i)	0.038	0.150	0.300	0.600
0.200(j)	0.050	0.200	0.400	0.800
0.300(n)		0.300	0.600	1.200

[a] (a) to (j) refer to lettering of photomicrographs on present ASTM chart. (n) indicates proposed additions.

(*e*) The above table be added to ASTM Method E 2 for purposes of clarification of chart values *versus* magnifications.

(*f*) Grain size be reported, as follows:

Grain Size, mm	Report to Nearest mm[a]
0.012 and smaller	0.001
Over 0.012 to 0.030	0.002
Over 0.030 to 0.070	0.005
Over 0.070 to 0.150	0.010
Over 0.150 to 0.300	0.025
Over 0.300 to 0.600	0.050
Over 0.600	0.100

[a] The allowable variation for reporting observations does not indicate the magnitude of the variation due to errors in the measuring devices, to human errors, or to differences between different observers, and should not be so construed.

RECOMMENDATIONS OF THE 1953 COMMITTEE

The following constitute the recommendations of the 1953 Task Group on Determination of Grain Size. They take into account the technological advances made in the art since 1940. For ease of comparison with the recommendations made by the earlier committee, the same sequence of grain size determination methods and paragraph numbers are used:

1. The intercept method is not the preferred method for equiaxed grains, but it is the best method available for determining grain size in cold worked material or structures having elongated grains.

2. The comparison method using transparencies gives more consistent results than the comparison method using opaque prints. These comparison methods are less time-consuming and less fatiguing than the Jeffries' planimetric method.

3. It is recommended that:

(*a*)

(1) The comparison method be adopted as the standard procedure for the determination of grain size of wrought copper and copper alloys. Comparison with transparencies is preferred to comparison with opaque prints.

(2) Standard grain size transparencies be made available through ASTM, similar to those now available for austenitic grain size in steels (ASTM Method E 19 - 46).[3]

(*b*) The Jeffries method be adopted as the referee method in case of disagreement.

(*c*) The following magnifications for comparison methods of grain size determination in copper and copper alloys be adopted as the preferred ones:

Grain Size	Magnification
0.002–0.012	300–500 ×
0.008–0.015	250–300 ×
0.010–0.150	75 ×
0.110–0.600	25 ×

(*d*) One new photomicrograph, illustrating 0.020-mm grain size, be added to the present plate No. 1 of ASTM Method E 79 - 49 T.[4]

(*e*) No further action be taken because a chart of grain size standards *versus* magnification is now printed in Method E 79, although 0.020-mm grain size is not included. This would be included automatically with the adoption of the 1953 recommendations contained in this report.

(*f*) Grain size be reported, as follows:

Grain Size, mm	Report to Nearest mm
0.002 to 0.008, inclusive	0.001
Over 0.008–0.014	0.002
Over 0.014–0.050	0.005
Over 0.050–0.150	0.01
Over 0.150–0.300	0.02
Over 0.300–0.600	0.05

APPENDIX A

HISTORY OF EARLIER WORK

During a meeting of Committee B-5 on Copper and Copper Alloys at the Wardman Park Hotel, Washington, D. C., March, 1940, considerable discussion developed over the methods and limits for obtaining and specifying the grain size of cartridge case cups and cartridge brass. This was in connection with a proposal to revise ASTM Method B 19–29[5] covering cartridge brass cups. Major C. H. Greenall (then Chairman of Committee B-5) placed the problem before Subcommittee I on Plate, Sheet, and Strip for review and recommendations. After careful consideration, Subcommittee I concluded that round-robin testing was the only practical way of obtaining sufficient information that might form the basis of recommended changes in grain-size determination.

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[3] Classification of Austenite Grain Size in Steels (E 19 - 46), 1952 Book of ASTM Standards, Part 1, p. 1435.

[4] Tentative Methods for Estimating the Average Grain Size of Wrought Copper and Copper-Base Alloys (E 79 - 49 T), 1952 Book of ASTM Standards, Part 2, p. 1144.

[5] Standard Specifications for Cartridge Brass (B 19 - 29), 1939 Book of ASTM Standards, Part I, p. 656.

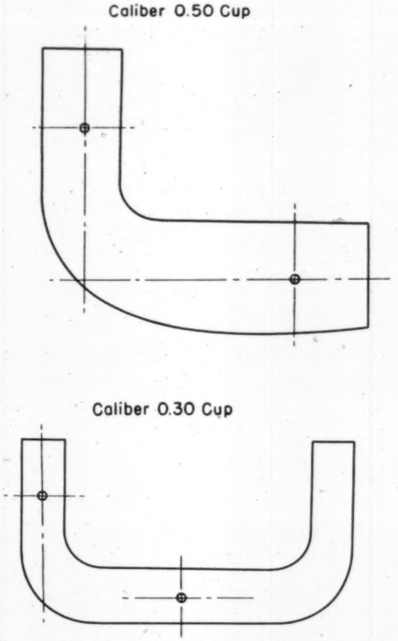

FIG. 1.—Locations Where Spot Readings Were Taken on Specimens Nos. 1 to 8 Inclusive.

It was also pointed out that such an examination would be of considerable benefit to all people concerned and would be a measure as to the reliability of the technique of the different laboratories involved. It would also be a check on the reliability and the case of interpretation of the ASTM Metallographic Grain Size Chart, Plate II, in Method E 2 - 36.[6]

A special committee of Subcommittee I was appointed to set up the program, study the results, and compile the final report and recommendations.

The Special Committee immediately made a canvass of the various laboratories that might be interested in participating in the round-robin test. It was finally decided that six manufacturers, two disinterested laboratories, and one arsenal be included. The following is the list of these participating laboratories in the order in which they received samples and made the determinations:

- Frankford Arsenal (Capt. L. S. Fletcher)
- General Electric Co. (G. H. Harnden)
- Revere Copper and Brass, Inc. (E. S. Bunn)
- Chase Brass and Copper Co. (L. A. Ward)
- American Brass Co. (C. H. Davis)
- Scovill Manufacturing Co. (W. B. Price)
- Bridgeport Brass Co. (R. S. Pratt)
- Bell Telephone Labs., Inc. (C. H. Greenall)
- Western Cartridge Co. (A. G. Schuricht)

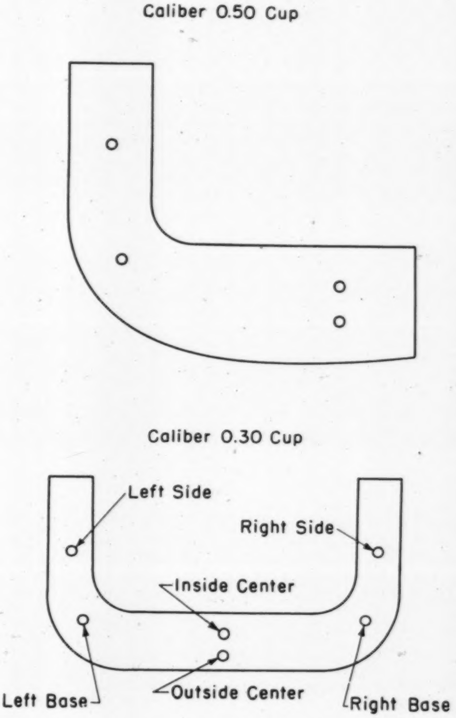

FIG. 2.—Locations Where Spot Readings Were Taken on Specimens Nos. 9 to 25 Inclusive.

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[6] Standard Rules Governing the Preparation of Micrographs of Metals and Alloys (E 2 - 36), 1936 Book of ASTM Standards, Part I, p. 763.

Because of the Frankford Arsenal's past experience with grain-size testing of cartridge case cups, the special committee relied heavily on that laboratory for advice and assistance. The Arsenal prepared prints showing the points at which the grain-size readings were to be taken (see Figs. 1 and 2). The work done at the arsenal indicated that the two areas in the bottom of the cup at the quarter points were equally as bad from the point of view of taking in some of the area abnormality as the center area in the bottom.

The grain size in the side wall and that area directly under the side wall at the plane where the base and the side wall join gave appreciably the same results. The two areas in the center of the base, one at a distance one third from the inside of the cup and the other at a distance two thirds from the inside of the cup, seemed to pick up the area of abnormality and the area of normal grain size.

Because of this, it was suggested that the investigation take in at least the areas on the side wall and the two areas in the center of the base, laterally, one of them one third of the way through and the other two thirds of the way through.

The Arsenal prepared the specimens and set up the instructions as to the correct procedure for reading grain size on various cups for the first series of tests. This included the reading of the grain sizes on 125 annealed cups, 75 representing caliber 0.30 and 50 representing caliber 0.50 cups.

The specimens were separated into five groups of 25 cups each. Each group was subdivided, the first eight having scribed lines at right angles to each other on the side wall and in the base, and the remaining seventeen without scribed lines.

The cups were manufactured from cartridge brass conforming to the requirements of U. S. Army Specification No. 57-172-2A (1939 revision).

The specification established the following limits for grain size under which the subject caliber 0.30 and caliber 0.50 cups used in these tests were procured at that time:

Caliber	Location	Grain Size, mm
Caliber 0.30 and 0.50....	Side wall	0.080 min, 0.140 max, ±0.010 on average
	Base	0.150 max, ±0.010 on average

The cups of the first five series of samples were fabricated from brass which conformed to the following limits on chemical analysis:

Copper................	68 to 71 per cent
Lead..................	0.07 per cent
Iron..................	0.05 per cent
Zinc..................	Balance
Other impurities........	0.150 per cent max

The cups were sectioned in half longitudinally and mounted in ivory bakelite. The mounted specimens were approximately 1¼ in. in diameter and ¾ in. long.

The specimens were then polished on abrasive papers of successive fineness and finished with levigated alumina on a special soft nappy fabric. Each specimen was etched with a fresh solution of ammoniacal peroxide in the proportion of 4:1 of ammonia and hydrogen peroxide. The specimens were identified on the back with a letter and number.

The caliber 0.30 cups were designated by the letters, *P*, *X*, and *L*, and the caliber 0.50 cups were identified as *G* and *K*. Each group of lettered specimens was selected from separate lots representing typical shipments from various brass manufacturers. The cups were packed in wooden boxes 10¼ by 10¼ by 2¼ in. in outside dimensions for shipment to the participating laboratories. The etched surfaces of the specimens were protected with lens paper.

Each participating laboratory was requested to use the following procedure:

1. A visual comparison of grain size as projected on the ground glass screen of a metallographic microscope shall be made with the grain size as shown on the ASTM metallographic grain size chart.

2. The magnification of the projected image shall be 75 ×.

3. A grain size smaller than 0.100 mm shall be reported to the nearest 0.005 mm

and a grain size larger than 0.100 mm to the nearest 0.01 mm.

4. Observations of grain size shall be indicated:

(*a*) Eight specimens in each set at positions indicated by scribed lines projected on the center of the field of observation showing a definite position within the general locations on the drawing (Fig. 1).

(*b*) Seventeen specimens in each set at positions indicated on the proposed drawings (Fig. 2).

5. Three determinations shall be made at each location indicated in 4(*a*) only, giving a maximum and minimum average grain size. The presence of any single grains that are abnormal in size shall be discounted, but if many are present in the various locations, their size, location, and dispersion shall be reported.

Grain-size results on the 125 specimens were forwarded to the chairman of the special subcommittee for review. The chairman forwarded the consolidated grain-size results to the Arsenal for review, correlation, and statistical analysis. This was done in order that the Arsenal might obtain advance information on what the results from all the laboratories had indicated.

A study of the data on these first tests as returned from each of the cooperating laboratories indicated quite conclusively that the instructions as originally sent out had not been followed. After discussing these data with representative members of the cooperating laboratories, it was concluded that these data should be ignored, and a supplementary program be set up with very specific instructions in which only ten specimens would be investigated for a second round-robin test. These samples were designated as the *Y* series.

For this second series of round-robin grain-size tests, the American Brass Co. supplied to the Arsenal ten samples of annealed brass of various grain sizes. These samples were presented as examples of what might be expected in cartridge brass as commercially made.

The composition of the brass was as follows:

Copper	68.99 per cent
Zinc	30.99 per cent
Lead	0.01 per cent
Iron	0.01 per cent

The material was cold-rolled from 0.170 to 0.130 in. and then annealed for 30 min at temperatures between 425 to 850 C.

These samples, designated as the *Y* series, were identified with a number and mounted in lucite (methylmethacrylate resin). About 0.02 in. of the surface of the brass was removed by hand grinding on No. 1 polishing paper. Subsequently, the specimens were polished on emery papers of successive fineness in the same manner as the previous groups in the first series and given a final polish with levigated alumina.

The specimens were etched with ammonia and hydrogen peroxide in the proportions of approximately 4:1.

After etching, a circle was engraved on the surface of the samples. This circle was about 1.13 mm in diameter, so that at a magnification of 75 diameters an area of about 85 mm in diameter could be observed. The object of these circles was to have spot grain-size readings made of the crystals encircled by the engraving.

Instructions to each of the participating laboratories required that the readings be made by the comparison method with the ASTM grain-size chart and that:

(*a*) For grain sizes smaller than 0.035 mm, the reading be recorded to the nearest 0.001 mm.

(*b*) For grain sizes between 0.035 mm and 0.100 mm, the reading be recorded to the nearest 0.005 mm.

(*c*) For grain sizes over 0.100 mm, the reading be recorded to the nearest 0.01 mm.

Each laboratory was asked to employ not less than three operators, and each operator was required to make not less than three readings on each specimen, staggering the time of reading on individual specimens so that no two readings were made successively, the preferred way being to make the readings on succeeding days.

Furthermore, each operator made readings at the same locations that were indicated, as stated before, by the circles inscribed on the etched specimens by the Arsenal.

Each reading, which was made by visual comparison, was taken on a projected area not less than 79.8 mm in diameter at 75 ×. In addition, if they cared to, the cooperating laboratories could make the readings with the use of transparencies (lantern slides), and this was done by one particular producer who customarily made grain-size determinations by this method. However, when the latter method was used, the results were analyzed separately and were not included in the statistical analysis of the original consolidated test data required to be sent by the cooperating laboratories to the chairman of the special subcommittee for review and analysis.

Each laboratory was provided with two different forms for recording the data. On the individual work sheet each operator recorded his average grain-size readings for each of the ten specimens. Since each operator was required to make three separate determinations on the specimens, preferably on different days, his data were listed on three individual work sheets.

The summary sheet listed the three determinations of each operator for each specimen, and also provided ample space for recording summation values, averages, standard deviations, and a description of the apparatus used.

Readings were taken also by the intercept method by some laboratories, and they were studied in a separate statistical analysis for comparison.

On the second group of ten samples (designated *Y*), the chairman appointed four different laboratories to make the statistical analysis. Representatives from General Electric Co., Chase Co., Bell Telephone Laboratories, and Frankford Arsenal constituted the staff of statisticians for making this study.

At a meeting of the members of the staff of statisticians who were analyzing the consolidated data on this series of grain-size tests, it was pointed out that practically every laboratory had again failed to follow instructions. The instructions required that on grain sizes less than 0.035 mm the estimation must be to the nearest 0.001 mm, for grain sizes over 0.035 mm to 0.100 mm, the reading should be to the nearest 0.005 mm, and for grain sizes over 0.100 mm, the reading should be to the nearest 0.01 mm.

It was decided at this meeting and agreed upon by all present to correct the readings in order to conform to the instructions. Furthermore, those figures which did not conform to the instructions should be rounded off. For instance, a reading like 0.036 mm should be corrected to 0.035 mm and one of 0.038 mm should be rounded off to 0.040 mm.

Most of the corrections were between 0.035 and 0.100 mm, where the instructions prescribed that the reading be to the nearest 0.005 mm, but actually the laboratories were estimating to the nearest 0.001 mm. Also, there were a few corrections on samples above 0.100 mm where the estimations were also to the nearest 0.005 mm.

One of the laboratories not only submitted grain-size results by the comparison method but also results of determinations by the intercept method. There was practically no difference in their results by either method; and it was the consensus that their intercept results should not be discarded.

There was some question as to how to analyze the results on samples Nos. 9 and 10 as there were no ASTM standards from which to estimate the grain sizes by comparison. With the exception of Frankford Arsenal, none of the laboratories gave an explanation as to how they made their determinations on these two samples. Some laboratories reported a grain-size figure with plus or minus signs, but it was not clear to the members what significance these plus or minus signs had. The chairman was of the opinion that the subcommittee should know how the estimations were made on the last two samples, and he proposed to write a letter to all laboratories except Frankford Arsenal to obtain this information.

It was concluded at this meeting that the analysis of the grain-size data should proceed according to the following plan:

1. Work up statistical data on specimens Nos. 1 to 8, inclusive, as corrected during the meeting. This applied only to data obtained from the comparison of actual specimens with the ASTM grain-size chart.

2. Same procedure as in No. 1 above on data obtained from comparison of specimens with transparencies (lantern slides). These

data should not be included with those of No. 1 during analysis.

3. Work up statistical data on specimens Nos. 1 to 10, inclusive, for laboratory No. 9. These data were obtained by the intercept method and should not be included with those of Nos. 1 and 2 above.

4. The chairman would make a check of all the laboratories to determine how the grain-size readings on specimens Nos. 9 and 10 were obtained. The results of this investigation would be forwarded to those persons analyzing the data, to be treated in the following manner:

(*a*) When the readings on specimens Nos. 9 and 10 were made by the comparison method, proceed as in No. 1 above.

(*b*) When the readings on specimens Nos. 9 and 10 were made by comparison with transparencies, proceed as in No. 2 above.

(*c*) When the readings on specimens Nos. 9 and 10 were made by the intercept method, proceed as in No. 3 above.

At a later meeting held by the statistical staff in the spring of 1942, it was agreed that in addition to the analysis which was to be made on the *Y* series further information be obtained on comparison with the transparency method and the intercept method. The final steps proposed then were to:

1. Omit data on specimens Nos. 9 and 10 in the analysis of the comparison method without the use of transparencies.

2. Analyze the data of results of grain size determined by the use of transparencies, but base the study on differences between operators only and not between laboratories. Data on specimens Nos. 9 and 10 would be omitted from the study.

3. Analyze the results obtained by the intercept method and base the study on differences between laboratories Nos. 1, 6, and 9, and the difference between operators in laboratory No. 9 only.

4. Study results obtained by the Jeffries method and base conclusions on the difference between three laboratories (No. 2, No. 6, and one unnamed laboratory). Readings between these laboratories would be based on results on the ten specimens using the following magnifications:

Nos. 1 to 5—At 75 × and 250 × in middle of inscribed circle.

Nos. 6, 7, and 8—At 75 × only.

Nos. 9 and 10—At 75 × and 25 ×. For 25 × inscribed circle will be in the center of the field.

The statistical analysis of the consolidated data referred to above is contained in Appendices B, C, D, and E of this report. Because of the mass of statistical data, it has been broken into five parts for ease of reference and is presented in the following order:

(*a*) Direct comparison method.

(*b*) Transparency method.

(*c*) Intercept method.

(*d*) Jeffries method.

(*e*) Composite of (*a*) and (*b*) above.

Information was requested from each of the participating laboratories in accordance with the decision made at the above mentioned meeting of the statisticians. A summary of the replies is presented herewith for purposes of information.

From Laboratory No. 1—No reply, although in a letter, which was sent in with their original data, the following statement was made:

> "You will note we determined the grain size not only by the conventional method but also by use of a viewing box arrangement, using transparencies for standards, these transparencies being made up from the ASTM standard negative."

CHAIRMAN'S NOTE.—From this it was assumed that for grain sizes over the maximum shown in ASTM Method E 2 the values were an assumption on the part of the operator, as they had been in the case of practically all of the other laboratories.

From Laboratory No. 2—"We would suggest eliminating all the grain size readings on specimens Nos. 9 and 10. The operators A and B did not estimate the grain size because there was no standard to follow. Operator C did make notations indicating that the grain size on specimen No. 9 would be about 0.400 to 0.500 mm and on specimen No. 10 about 0.800 to 1.6 mm. It is not in accord with the Jeffries method to try to estimate grain size when there are such a small number of grains within the specified circle, namely, 79.8 mm."

From Laboratory No. 3—"Would advise that the grain sizes exceeding 0.200 mm reported by us were estimated by simple extrapolation from the series of standard micrographs, Plate 3, ASTM Designation E 2 - 39 T. So far as we were aware, no other method of estimation would have come within the rules of the experiment. No particular degree of accuracy was applied in the results as reported."

From Laboratory No. 4—"In going over our data, we find that in only one or two instances, with the exception of the last sample, have we reported grain sizes above 0.220 mm. These figures above 0.200 were approximated in much the same manner that the figures between the Standard's [E 2] figures were approximated. On the last sample, it was obvious that the grain size was much greater than was covered by our standards. We therefore did not attempt to make any determinations for grain size by the method which we have used, other than to indicate that the grain size was greater than 0.250 mm. We might perhaps have been more justified if we had reported them as 0.200 plus mm. In other words, we made no attempt to determine the grain size in the last sample because the method which we normally use does not permit this determination. We believe there is only one way in which grain size determination could be made on such samples, and that is by reducing the magnification used. There was nothing in our instructions to suggest the use of any other method than the standard method and, therefore, we did not make any attempt to determine these grain sizes. Personally, I believe that the last sample of the group should not have been included in the group and that your best procedure would be to drop consideration of it in view of the probable confused data which you have for this sample."

From Laboratory No. 5—"I wish to advise you that all of our grain sizes above 200 [0.200 mm] were based on estimation. This estimation was rough and based on comparison of the largest ASTM grain size on the chart. This was necessary as there were no standard ASTM grain size charts available for comparison in these larger sizes."

From Laboratory No. 6—No further information required.

From Laboratory No. 7—"The three operators responsible for the values submitted by the Laboratory report that readings on specimens Nos. 9 and 10 were obtained only by visual comparison with the standard ASTM grain size chart E 2 - 39 T, each operator using his best judgment of the comparative size of the grain shown in Plate J of this chart with those found in the two samples under observation. Since the values reported by the Laboratories did not indicate a range of variations by plus or minus signs, we are not now attempting to show what this range might be."

From Laboratory No. 8—"The values reported are estimations based on the comparison of the grains shown *versus* the largest grains shown in the ASTM grain size chart E 2 - 39 T."

From Laboratory No. 9—"Our reason for not answering your previous letter was that we were under the impression that, as all the necessary data had been forwarded to you, it would not be necessary to answer your inquiry. If you will refer to the data which was sent to you, you will find that all of the information which you need was included with the original data."

APPENDIX B

STATISTICAL ANALYSIS OF 1940 RESULTS FOR DIRECT COMPARISON METHOD

Scope:

This memorandum presents an analysis of the data obtained for eight of the ten series *Y* brass specimens by the direct comparison method for the determination of grain size. These data cover grain size determinations for ten different specimens covering a range of about 0.030 to 0.700 mm for the average grain diameter secured by from three to five different operators at nine different laboratories. This progress report describes the nature of the data and presents a statistical analysis and summary of the results obtained for the first eight specimens. Results for specimens Nos. 9 and 10 having large grain sizes were so incomplete and varied that the subcommittee agreed to omit them from this progress report.

Nature of Data:

Data giving grain size in millimeters were obtained by the nine laboratories participating in this study for the same ten different specimens prepared by the Frankford Arsenal. The area on each specimen was clearly scribed and explicit written instructions describing the procedure by which the grain size was to be determined and recorded accompanied the specimens. These instructions stated:

> "For grain sizes smaller than 0.035 mm, report to the nearest 0.001 mm.
>
> For grain sizes 0.035 to 0.100 mm inclusive, report to the nearest 0.005 mm.
>
> For grain sizes larger than 0.100 mm, report to the nearest 0.010 mm."

Two forms were furnished to provide a common system for recording the data. Form No. 1, "Individual Work Sheet," was designed for use in taking each set of ten measurements by the direct comparison method by each operator and also provided for any special readings obtained by other methods. Each set of measurements was recorded on a separate form by each operator. Form No. 2, "Summary Sheet," provided for listing the three determinations of each operator for each specimen for a single method and provided space for describing the apparatus used in the method employed. Each laboratory filled out one of these forms for the results obtained by the direct comparison method. Special readings obtained by a different method were listed on a second form.

TABLE I.—APPARATUS USED IN DETERMINATIONS OF GRAIN SIZE BY DIRECT COMPARISON METHOD.

Laboratory	Objective	Ocular	Bellows Extension	Source of Illumination	Diameter of Projected Circle	Additional Information
No. 1....	Microtar 8	7 ×	57.5 mm	Carbon arc	85 mm	...
No. 2....	16 mm Achromatic	5 × Hyperplane	11½ in.	Carbon arc	4¾ in.	B & L Metalloscope I.L.S.
No. 3....	16 mm	5 ×	27 cm	D-c arc	85 mm	...
No. 4....	22.7	12.5 ×	...	Tungsten arc	115 mm	Euscope
No. 5....	16 mm	5 ×	30.5 cm	Tungsten filament	85 mm	...
No. 6....	B & L 22.7 mm 6 ×	12.5 ×—B & L	...	GE-Hg vapor bulb	85 mm	U-Scope
No. 7....	16 mm	6 ×	21.8 cm	D-c arc	83 mm	Mag. 75 ×, Zeiss Martens microscope
No. 8....	35 mm	6 ×	43 cm	Arc	200 mm	Leitz Micrometallograph, type MM
No. 9....	8.0 ×—0.20 N.A.	5 × Huy.	47.0 cm	Carbon arc	163 mm	Mag. 75 × B & L research metallographic equipment

Data based on the direct comparison method (ASTM Method E 2 - 39 T)[2] were submitted by all nine laboratories. Each laboratory is designated by a number, 1 to 9, inclusive. Each operator at each laboratory is designated by a letter, A, B, C, D, or E. The number of operators at each laboratory varied from three to five, a total of 32 operators reporting from the nine laboratories.

Table I presents a summary of the description of the apparatus used in the direct comparison method by each of the nine laboratories.

Control Analysis of Results:

Following the steps outlined on Form 2,

TABLE II.—SUMMARY OF AVERAGE AND STANDARD DEVIATION VALUES FOR EACH SPECIMEN BY LABORATORIES AND BY OPERATORS.

Average Grain Diameter in Millimeters.
Direct Comparison Method.

Laboratory	Operator A		Operator B		Operator C		Operator D		Operator E		All Operators			
	X	σ_w	X	σ_w	X	σ_w	X	σ_w	X	σ_w	X	σ_o	$\sigma_{\overline{X}}$	$\overline{\sigma}_w$
							SPECIMEN NO. 1							
No. 1	0.0267^b	0.00623	0.0283^b	0.00125	0.0247^b	0.00340	0.0300^b	0	0.0300^b	0.00163	0.0279^b	0.00389	0.00212	0.00250
No. 2	0.0337	0.00094	0.0307	0.00094	0.0333	0.00240					0.0326	0.00206	0.00133	0.00143
No. 3	0.0350	0	0.0400^a	0	0.0383^a	0.00236					0.0378^a	0.00212	0.00208	0.00079
No. 4	0.0320	0	0.0320	0	0.0330	0	0.0327	0.00045			0.0324	0.00049	0.00044	0.00011
No. 5	0.0382^a	0.00236	0.0327	0.00045	0.0400^a	0					0.0370^a	0.00343	0.00312	0.00094
No. 6	0.0300^b	0	0.0300^b	0	0.0317	0.00235	0.0300^b	0	0.0300	0	0.0303^b	0.00125	0.00094	0.00047
No. 7	0.0293^b	0.00095	0.0350	0.00408	0.0320	0.00141					0.0321	0.00345	0.00217	0.00215
No. 8	0.0350	0	0.0320	0.00141	0.0417^a	0.00235					0.0362^a	0.00434	0.00415	0.00125
No. 9	0.0400^a	0	0.0400^a	0	0.0350	0					0.0383^a	0.00236	0.00375	0
							SPECIMEN NO. 2							
No. 1	0.0383^b	0.00236	0.0340^b	0.00141	0.0350^b	0	0.0350^b	0	0.0367^b	0.00235	0.0358^b	0.00223	0.00152	0.00122
No. 2	0.0400	0	0.0450	0	0.0417	0.00235					0.0422	0.00249	0.00209	0.00078
No. 3	0.0450^a	0	0.0500^a	0.00408	0.0483^a	0.00236					0.0478^a	0.00310	0.00207	0.00215
No. 4	0.0400	0	0.0400	0	0.0400	0	0.0400	0			0.0400	0	0	0
No. 5	0.0433	0.00236	0.0450^a	0	0.0500^a	0					0.0461^a	0.00314	0.00283	0.00079
No. 6	0.0417	0.00235	0.0400	0	0.0433	0.00236	0.0400	0	0.0400	0	0.0410	0.00200	0.00133	0.00094
No. 7	0.0400	0	0.0417	0.00235	0.0433	0.00236					0.0417	0.00235	0.00135	0.00157
No. 8	0.0417	0.00235	0.0450^a	0	0.0467^a	0.00235					0.0444	0.00284	0.00209	0.00157
No. 9	0.0450^a	0	0.0450^a	0	0.0483^a	0.00236					0.0461^a	0.00208	0.00119	0.00079
							SPECIMEN NO. 3							
No. 1	0.0467^b	0.00156	0.0417^b	0.00471	0.0450^b	0	0.0467^b	0.00235	0.0450^b	0	0.0450^b	0.00316	0.00227	0.00172
No. 2	0.0450^b	0	0.0533	0.00236	0.0567	0.00471					0.0517	0.00577	0.00491	0.00236
No. 3	0.0517	0.00145	0.0567	0.00471	0.0533	0.00472					0.0539	0.00458	0.00208	0.00363
No. 4	0.0450^b	0	0.0450^b	0	0.0500	0	0.0450^b	0			0.0462^b	0.00305	0.00216	0
No. 5	0.0567	0.00623	0.0550	0	0.0700^a	0					0.0606^a	0.00761	0.00671	0.00208
No. 6	0.0483	0.00472	0.0550	0	0.0617^a	0.00471	0.0650^a	0	0.0633^a	0.00237	0.0587^a	0.00694	0.00618	0.00236
No. 7	0.0483^b	0.00236	0.0433	0.00236	0.0517	0.00235					0.0478	0.00414	0.00342	0.00236
No. 8	0.0550	0.00707	0.0567	0.00235	0.0600^a	0					0.0572	0.00478	0.00209	0.00314
No. 9	0.0500	0	0.0550	0	0.0583^a	0.00237					0.0544	0.00369	0.00343	0.00079

SPECIMEN No. 4

No. 1	0.0617	0.00235	0.0483[b]	0.00236	0.0550[b]	0	0.0583	0.00237	0.0583	0.00237	0.0563[b]	0.00499	0.00437	0.00189
No. 2	0.0500[b]	0	0.0633	0.00141	0.0667	0.00471					0.0600	0.00773	0.00720	0.00204
No. 3	0.0600	0.00408	0.0683[a]	0.00237	0.0600	0.00707					0.0628	0.00711	0.00391	0.00451
No. 4	0.0600	0	0.0500[b]	0	0.0617	0.00235	0.0533[b]	0.00236			0.0562[b]	0.00558	0.00478	0.00143
No. 5	0.0717[a]	0.00235	0.0650	0	0.0800[a]	0					0.0722[a]	0.00629	0.00614	0.00078
No. 6	0.0583	0.00850	0.0633	0.00237	0.0700[a]	0.00408	0.0733[a]	0.00237	0.0700[a]	0	0.0670	0.00969	0.00859	0.00346
No. 7	0.0633	0.00472	0.0667	0.00235	0.0667	0.00235					0.0656	0.00370	0.00160	0.00314
No. 8	0.0667	0.00235	0.0650	0	0.0667	0.00235					0.0661	0.00208	0.00089	0.00157
No. 9	0.0600	0	0.0650	0	0.0650	0					0.0633	0.00237	0.00237	0

SPECIMEN No. 5

No. 1	0.0783	0.00237	0.0650[b]	0	0.0717[b]	0.00235	0.0783	0.00472	0.0750	0.00707	0.0737[b]	0.00605	0.00487	0.00330
No. 2	0.0633[b]	0.00313	0.0783	0.00236	0.0783	0.00328					0.0733	0.00745	0.00707	0.00292
No. 3	0.0833	0.00237	0.0783	0.00237	0.0817	0.00471					0.0811	0.00393	0.00208	0.00315
No. 4	0.0733	0.00237	0.0650[b]	0	0.0767	0.00235	0.0750	0			0.0725[b]	0.00479	0.00449	0.00118
No. 5	0.0900[a]	0.00408	0.0900[a]	0.00707	0.0883[a]	0.00237					0.0894[a]	0.00497	0.00079	0.00451
No. 6	0.0800	0	0.0767	0.00236	0.0950[a]	0	0.0883[a]	0.00236	0.0900[a]	0	0.0860[a]	0.00688	0.00672	0.00094
No. 7	0.0733	0.00471	0.0750	0.0108	0.0783	0.00236					0.0756	0.00724	0.00208	0.00596
No. 8	0.0833	0.00236	0.0833	0.00236	0.0833	0.00471					0.0833	0.00333	0	0.00314
No. 9	0.0700[b]	0	0.0800	0	0.0800	0					0.0767	0.00471	0.00471	0

SPECIMEN No. 6

No. 1	0.100	0	0.0883[b]	0.00624	0.0900[b]	0.00408	0.100	0.00816	0.0933	0.00624	0.0943[b]	0.00750	0.00465	0.00494
No. 2	0.0867[b]	0.00236	0.0983	0.00236	0.110[a]	0					0.0983	0.00972	0.00953	0.00158
No. 3	0.103	0.00472	0.110[a]	0	0.107	0.00471					0.1067	0.00471	0.00285	0.00314
No. 4	0.0900[b]	0	0.0933	0.00237	0.103	0.00472	0.0917[b]	0.00234			0.0946[b]	0.00566	0.00504	0.00238
No. 5	0.110[a]	0.00816	0.107	0.00471	0.120[a]	0.00816					0.1122[a]	0.00916	0.00567	0.00701
No. 6	0.0950	0.00408	0.110[a]	0	0.103	0.00471	0.0983	0.00236	0.110[a]	0	0.1033	0.00675	0.00606	0.00223
No. 7	0.107	0.00471	0.105	0.0108	0.0983	0.00236					0.1033	0.00782	0.00360	0.00596
No. 8	0.0933	0.00236	0.110[a]	0	0.0950	0.00408					0.0994	0.00797	0.00749	0.00215
No. 9	0.100	0	0.110[a]	0	0.110[a]	0					0.1067	0.00471	0.00471	0

(Continued on p. 186)

TABLE II.—*Concluded.*

Laboratory	Operator A		Operator B		Operator C		Operator D		Operator E		All Operators			
	$\overline{X}$	σ_w	$\overline{X}$	σ_w	$\overline{X}$	σ_w	$\overline{X}$	σ_w	$\overline{X}$	σ_w	$\overline{X}$	σ_o	$\sigma_{\overline{X}}$	$\bar{\sigma}_w$
SPECIMEN NO. 7														
No. 1........	0.147	0.00942	0.153	0.0125	0.140	0.00816	0.157	0.00470	0.133[b]	0.00472	0.146	0.0120	0.00854	0.00790
No. 2........	0.147	0.00471	0.167[a]	0.00470	0.150	0.00816					0.154	0.0100	0.00850	0.00492
No. 3........	0.147	0.00470	0.167[a]	0.00470	0.147	0.00470					0.153	0.0105	0.00942	0.00470
No. 4........	0.133[b]	0.00472	0.147	0.00470	0.147	0.00942	0.143	0.00472			0.142	0.0145	0.00572	0.00589
No. 5........	0.153	0.00472	0.153	0.00472	0.163	0.0170					0.157	0.0115	0.00471	0.00881
No. 6........	0.187[a]	0.0126	0.150	0	0.167[a]	0.0236	0.140	0	0.157	0.00471	0.160	0.0200	0.0159	0.00818
No. 7........	0.150	0	0.190[a]	0.00816	0.157	0.00471					0.166	0.0183	0.0175	0.00429
No. 8........	0.153	0.00471	0.150	0	0.147	0.00471					0.150	0.00471	0.00272	0.00314
No. 9........	0.140	0	0.150	0	0.160	0					0.150	0.00816	0.00816	0
SPECIMEN NO. 8														
No. 1........	0.173	0.0189	0.163[b]	0.00473	0.203	0.0125	0.200	0	0.193	0.00943	0.187	0.0192	0.0156	0.00911
No. 2........	0.167[b]	0.00470	0.190	0.00816	0.197	0.00470					0.184	0.0142	0.0129	0.00585
No. 3........	0.180	0	0.180	0	0.183	0.0170					0.181	0.00994	0.00141	0.00567
No. 4........	0.170[b]	0.00816	0.173	0.00472	0.173	0.00472	0.170[b]	0			0.172[b]	0.00141	0.00150	0.00440
No. 5........	0.203	0.0125	0.187	0.0205	0.217[a]	0.00471					0.202[a]	0.0187	0.0123	0.0126
No. 6........	0.243[a]	0.0158	0.180	0	0.190	0.0141	0.160[b]	0	0.193	0.0148	0.193	0.0289	0.0276	0.00894
No. 7........	0.200	0	0.200	0	0.187	0.00471					0.196[a]	0.00685	0.00629	0.00123
No. 8........	0.173	0.00471	0.183	0.00471	0.167[b]	0.00471					0.174[b]	0.00831	0.00682	0.00471
No. 9........	0.200	0	0.200	0	0.200	0					0.200[a]	0	0	0

NOTES AND DEFINITIONS OF SYMBOLS:

Nine laboratories involved in study designated by Nos. 1 to 9, inclusive.

Operators at each laboratory designated by letters A, B, C, D, and E.

$\overline{X}$ = average arithmetic mean.

σ_w = variation within group of observations for a single operator; standard deviation within group.

$\bar{\sigma}_w$ = average standard deviation within group.

σ_o = over-all variation within a single laboratory; over-all standard deviation.

$\sigma_{\overline{X}}$ = variation between average determinations of operators in a single laboratory; standard deviation between operators (designated as σ_b hereafter).

[a] Average or standard deviation significantly greater than expected value for all laboratories combined; above larger 3 σ control limit.

[b] Average or standard deviation significantly less than expected value for all laboratories combined; below smaller 3 σ control limit.

TABLE III.—SUMMARY OF AVERAGE AND STANDARD DEVIATION VALUES USED IN CONTROL ANALYSIS FOR EACH SPECIMEN BY LABORATORIES.

Average Grain Diameter in Millimeters.

Direct Comparison Method.

Laboratory	Number of Operators	Number of Observations	Average, $\overline{X}$	Standard Deviation Within Individual Operators		Standard Deviation Between Individual Operators		Over-all Standard Deviation	
				Average, $\bar{\sigma}_w$	Corrected, σ'_w	σ_b	Corrected, σ'_b	σ_o	Corrected, σ'_o
SPECIMEN No. 1									
No. 1.....	5	15	0.0279	0.00250		0.00212		0.00336	
No. 2.....	3	9	0.0326	0.00143		0.00133		0.00224	
No. 3.....	3	9	0.0378	0.00079		0.00208		0.00212	
No. 4.....	4	12	0.0324	0.00011		0.00044		0.00049	
No. 5.....	3	9	0.0370	0.00094		0.00312		0.00343	
No. 6.....	5	15	0.0303	0.00047		0.00094		0.00125	
No. 7.....	3	9	0.0321	0.00215		0.00217		0.00345	
No. 8.....	3	9	0.0362	0.00125		0.00415		0.00434	
No. 9.....	3	9	0.0383	0		0.00375		0.00375	
	32	96	0.0332	0.00109	0.00150	0.00209	0.00301	0.00271	0.00281
SPECIMEN No. 2									
No. 1.....	5	15	0.0358	0.00122		0.00152		0.00223	
No. 2.....	3	9	0.0422	0.00078		0.00209		0.00249	
No. 3.....	3	9	0.0478	0.00215		0.00207		0.00310	
No. 4.....	4	12	0.0400	0		0		0	
No. 5.....	3	9	0.0461	0.00079		0.00283		0.00314	
No. 6.....	5	15	0.0410	0.00094		0.00133		0.00200	
No. 7.....	3	9	0.0417	0.00157		0.00135		0.00235	
No. 8.....	3	9	0.0444	0.00157		0.00209		0.00284	
No. 9.....	3	9	0.0461	0.00079		0.00119		0.00208	
	32	96	0.0422		0.00146	0.00161	0.00216	0.00225	0.00234
SPECIMEN No. 3									
No. 1.....	5	15	0.0450	0.00172		0.00227		0.00316	
No. 2.....	3	9	0.0517	0.00236		0.00491		0.00577	
No. 3.....	3	9	0.0539	0.00363		0.00208		0.00458	
No. 4.....	4	12	0.0462	0		0.00216		0.00305	
No. 5.....	3	9	0.0606	0.00208		0.00671		0.00761	
No. 6.....	5	15	0.058	0.00236		0.00618		0.00694	
No. 7.....	3	9	0.0478	0.00236		0.00342		0.00414	
No. 8.....	3	9	0.0572	0.00314		0.00209		0.00478	
No. 9.....	3	9	0.0544	0.00079		0.00343		0.00369	
	32	96	0.0525	0.00203	0.00281	0.00378	0.00501	0.00497	0.00531
SPECIMEN No. 4									
No. 1.....	5	15	0.0563	0.00189		0.00437		0.00499	
No. 2.....	3	9	0.0600	0.00204		0.00720		0.00773	
No. 3.....	3	9	0.0628	0.00451		0.00391		0.00711	
No. 4.....	4	12	0.0562	0.00118		0.00478		0.00558	
No. 5.....	3	9	0.0722	0.00078		0.00614		0.00629	
No. 6.....	5	15	0.0670	0.00377		0.00859		0.00969	
No. 7.....	3	9	0.0656	0.00314		0.00160		0.00370	
No. 8.....	3	9	0.0661	0.00123		0.00089		0.00208	
No. 9.....	3	9	0.0633	0		0.00237		0.00237	
	32	96	0.0629	0.00215	0.00297	0.00444	0.00579	0.00547	0.00614

(Continued on p. 188)

TABLE III.—*Concluded.*

Laboratory	Number of Operators	Number of Observations	Average, $\overline{X}$	Standard Deviation Within Individual Operators		Standard Deviation Between Individual Operators		Over-all Standard Deviation	
				Average, $\bar{\sigma}_w$	Corrected, σ'_w	σ_b	Corrected, σ'_b	σ_o	Corrected, σ'_o
SPECIMEN NO. 5									
No. 1.....	5	15	0.0737	0.00330		0.00487		0.00605	
No. 2.....	3	9	0.0733	0.00292		0.00707		0.00745	
No. 3.....	3	9	0.0811	0.00315		0.00208		0.00393	
No. 4.....	4	12	0.0725	0.00118		0.00449		0.00479	
No. 5.....	3	9	0.0894	0.00451		0.00079		0.00497	
No. 6.....	5	15	0.0860	0.00094		0.00672		0.00688	
No. 7.....	3	9	0.0756	0.00596		0.00208		0.00724	
No. 8.....	3	9	0.0833	0.00314		0		0.00333	
No. 9.....	3	9	0.0767	0		0.00471		0.00471	
	32	96	0.0790	0.00263	0.00363	0.00361	0.00468	0.00544	0.00598
SPECIMEN NO. 6									
No. 1.....	5	15	0.0943	0.00494		0.00465		0.00750	
No. 2.....	3	9	0.0983	0.00157		0.00953		0.00972	
No. 3.....	3	9	0.1067	0.00314		0.00285		0.00471	
No. 4.....	4	12	0.0946	0.00238		0.00504		0.00566	
No. 5.....	3	9	0.1122	0.00701		0.00567		0.00916	
No. 6.....	5	15	0.1033	0.00223		0.00606		0.00675	
No. 7.....	3	9	0.1033	0.00596		0.00360		0.00782	
No. 8.....	3	9	0.0994	0.00215		0.00749		0.00797	
No. 9.....	3	9	0.1067	0		0.00471		0.00471	
	32	96	0.1015	0.00335	0.00463	0.00552	0.00711	0.00715	0.00766
SPECIMEN NO. 7									
No. 1.....	5	15	0.146	0.00790		0.00854		0.0120	
No. 2.....	3	9	0.154	0.00492		0.00850		0.0100	
No. 3.....	3	9	0.153	0.00470		0.00942		0.0105	
No. 4.....	4	12	0.142	0.00589		0.00572		0.0145	
No. 5.....	3	9	0.157	0.00881		0.00471		0.0115	
No. 6.....	5	15	0.160	0.00818		0.01590		0.0200	
No. 7.....	3	9	0.166	0.00429		0.01750		0.0183	
No. 8.....	3	9	0.150	0.00314		0.00272		0.0047	
No. 9.....	3	9	0.150	0		0.00816		0.0082	
	32	96	0.153	0.00542	0.00749	0.00893	0.0117	0.0121	0.0136
SPECIMEN NO. 8									
No. 1.....	5	15	0.187	0.00911		0.0156		0.0192	
No. 2.....	3	9	0.184	0.00585		0.0129		0.0142	
No. 3.....	3	9	0.181	0.00567		0.0014		0.0099	
No. 4.....	4	12	0.172	0.00440		0.0015		0.0014	
No. 5.....	3	9	0.202	0.0126		0.0123		0.0187	
No. 6.....	5	15	0.193	0.00894		0.0276		0.0289	
No. 7.....	3	9	0.196	0.00157		0.0063		0.0068	
No. 8.....	3	9	0.174	0.00471		0.0068		0.0083	
No. 9.....	3	9	0.200	0		0		0	
	32	96	0.188	0.00622	0.00859	0.00949	0.0122	0.0122	0.0145

"Summary Sheet," average and standard deviation values were determined for results from each operator and from all operators combined for each specimen. Using the average value for each operator, the variation between operators at a single laboratory was determined as a standard deviation (σ), the root mean square deviation for averages. Table II summarizes these results. This table also includes average values of the standard deviation between operators, used to determine control limits. These results are tabulated for each specimen, and all values outside the 3 σ control limits are designated as a (above) and b (below).

TABLE IV.—NUMBER AND PERCENTAGE OF AVERAGE VALUES WITHIN CONTROL LIMITS.

Eight Specimens, Nine Laboratories.
Average Grain Diameter.
Direct Comparison Method.

Laboratory	Over-all Average				Averages for Individual Operators				
	Above[a]	Below[b]	Within Control Limits		No. of Operators	Above[a]	Below[b]	Within Control Limits	
			Number	Per Cent				Number	Per cent
No. 1.......	0	6	2	25.0	5	0	23	17	42.5
No. 2.......	0	0	8	100.0	3	2	5	17	70.8
No. 3.......	2	0	6	75.0	3	8	0	16	66.7
No. 4.......	0	6	2	25.0	4	0	11	21	65.6
No. 5.......	7	0	1	12.5	3	13	0	11	45.8
No. 6.......	2	1	5	62.5	5	14	5	21	52.5
No. 7.......	1	0	7	87.5	3	1	2	21	87.5
No. 8.......	1	1	6	75.0	3	5	1	18	75.0
No. 9.......	3	0	5	62.5	3	8	1	15	62.5
	—	—	—	——	—	—	—	——	——
	16	14	42	58.3	32	51	48	157	61.3

[a] Denotes that average value is greater than upper 3 σ control limits.
[b] Denotes that average value is less than lower 3 σ control limits.

Table III lists the average value for each specimen determined at each laboratory and the standard deviation values used for control analyses. Any of these average values outside its 3 σ control limits is designated as a (above) and b (below). These results, together with those given in Table II, indicate in tabular form similar results to those indicated by the use of control charts for averages.

Table IV presents a summary of the consistency of the results for the laboratories as compared with the over-all results. These findings are presented in terms of the number and percentage values outside the 3 σ control limits. A study of this table indicates which laboratories are most consistent with respect to average in comparison with expected values for all laboratories combined.

TABLE V.—RANKING OF LABORATORIES WITH RESPECT TO CONTROL BASED ON EXPECTED VALUES FOR ALL LABORATORIES.

Average Grain Diameter.
Direct Comparison Method.

Laboratory	Rank for Over-all Average	Rank for Individual Operator's Averages	Sum of Ranks	Final Ranking	
				Rank	Laboratory
No. 1.....	7.5	9	16.5	1	7
No. 2.....	1	3	4.0	2	2
No. 3...	3.5	4	7.5	3	8
No. 4.....	7.5	5	12.5	4	3
No. 5.....	9	8	17.0	5	9
No. 6.....	5.5	7	12.5	6.5	4
No. 7.....	2	1	3.0	6.5	6
No. 8.....	3.5	2	5.5	8	1
No. 9.....	5.5	6	11.5	9	5

Analysis of Results by Ranking:

The results for control and the average and standard deviation values obtained in this study may be simplified by means of ordering the laboratories. This is termed the method of ranking. The percentage values in Table IV of the preceding section for over-all average values and individual operator's average values that were found to be within the 3 σ control limits may be used to rank the laboratories as indicated in Table V. Where two laboratories have the same percentage values, the average of the two ranks are used for each laboratory.

Using average and over-all standard deviation values for the eight specimens and using rank 1 for the smallest value in both instances, the laboratories may be ranked as indicated in Table VI. This shows which laboratory on the average tends to record the smallest values and also which laboratory tends to have smaller over-all standard deviation values—that is, less variability with respect to all values on the average.

TABLE VI.—RANKING OF LABORATORIES WITH RESPECT TO OVER-ALL AVERAGE AND OVER-ALL STANDARD DEVIATION VALUES.

Results for Eight Specimens and for All Specimens Combined.

Average Grain Diameter.

Direct Comparison Method.

Laboratory	Specimen No. 1		Specimen No. 2		Specimen No. 3		Specimen No. 4		Specimen No. 5		Specimen No. 6		Specimen No. 7		Specimen No. 8		Sum of Ranks		Final Ranking		
																				Laboratory	
	$\overline{X}$	σ	$\overline{X}$	σ	$\overline{X}$	σ	$\overline{X}$	σ	$\overline{X}$	σ	$\overline{X}$	σ	$\overline{X}$	σ	$\overline{X}$	σ	$\overline{X}$	σ	Rank	$\overline{X}$	σ
No. 1......	1	5	1	4	1	2	2	4	3	6	1	5	2	6	5	8	16	40	1	4	9
No. 2......	5	4	5	6	4	7	3	8	2	9	3	9	6	3	4	6	32	52	2	1	4
No. 3......	8	3	9	8	5	5	4	7	6	2	7	1	5	4	3	5	47	35	3	2	3
No. 4......	4	1	2	1	2	1	1	5	1	4	2	3	1	7	1	2	14	24	4	7	8
No. 5......	7	6	7	9	9	9	9	6	9	5	9	8	7	5	9	7	66	55	5	8	1
No. 6......	2	2	3	2	8	8	8	9	8	7	6	4	8	9	6	9	49	50	6	3	7
No. 7......	3	7	4	5	3	4	6	3	4	8	5	6	9	8	7	3	41	44	7	6	6
No. 8......	6	9	6	7	7	6	7	1	7	1	4	7	3	1	2	4	42	36	8	9	2
No. 9......	9	8	8	3	6	3	5	2	5	3	8	2	4	2	8	1	53	24	9	5	5

NOTE.—1 denotes smallest value, . . . 9 denotes largest value.

Determinations were made by 32 different operators at the nine laboratories. Their average values have been ranked in order giving 1 to the smallest value and 32 to the largest value. Table VII presents a summary of results for the individual operators. Where average values were the same for several operators, the average of the ranks involved were assigned to each operator.

The results on Table VII indicate that operator C of laboratory No. 5 reads high consistently, while operator B of laboratory No. 1 reads low consistently. A study of these results indicates that there is wide variation between the operators at a single laboratory for specimens Nos. 7 and 8, whereas the variation between operators at a single laboratory is much smaller for the other six specimens. This may be due to the fact that the average grain sizes for specimens Nos. 7 and 8 are much larger and that, under the instructions, values are recorded only to the nearest 0.010 mm for grain sizes larger than 0.100 mm.

Analysis of Distributions and Variations of Results:

Distributions of the actual observations for each of the nine laboratories and for all laboratories combined for each of the eight specimens are presented on Fig. 3.

For specimens Nos. 1, 2, and 6, Figs. 3 and 4 give observations for the actual cell widths required to be used under the instructions noted in the section on Nature of Data. Distributions using equal cell widths are given by the dotted lines on the two figures so that it is possible to visualize the nature of the distributions. These charts indicate the nature of the distributions for each laboratory and further substantiate the findings of this study.

Although the analysis by the control chart method indicated lack of control so that the conditions under which the method by analysis of variances may be applied are not satisfied, the data were analyzed by this method. For each specimen a test was made to determine whether a significant difference was indicated between the variance between laboratories and the variance within laboratories based on the criteria $P = 0.01$ and $P = 0.05$. A similar test was made for each laboratory to determine whether a significant difference was indicated between the variance between operators and the variance within an operator based on the criteria $P = 0.01$ and $P = 0.05$. A summary of these results is given in Table VIII. Table IX presents values of the variance on which the results in Table VIII were based. The standard procedure for analysis of variance was used, where n_1 and n_2 values in terms of number of degrees of freedom were tabulated in each computation, and a z value was found and compared with the z values for $P = 0.01$ and $P = 0.05$, read from Table VI of R. A. Fisher's "Statistical Methods for Research Workers."

A study was made of the contribution of the three variations,

1. Variation within single operator,

TABLE VII.—RANKING OF OPERATORS AND LABORATORIES WITH RESPECT TO AVERAGE VALUES OBTAINED BY EACH OPERATOR.

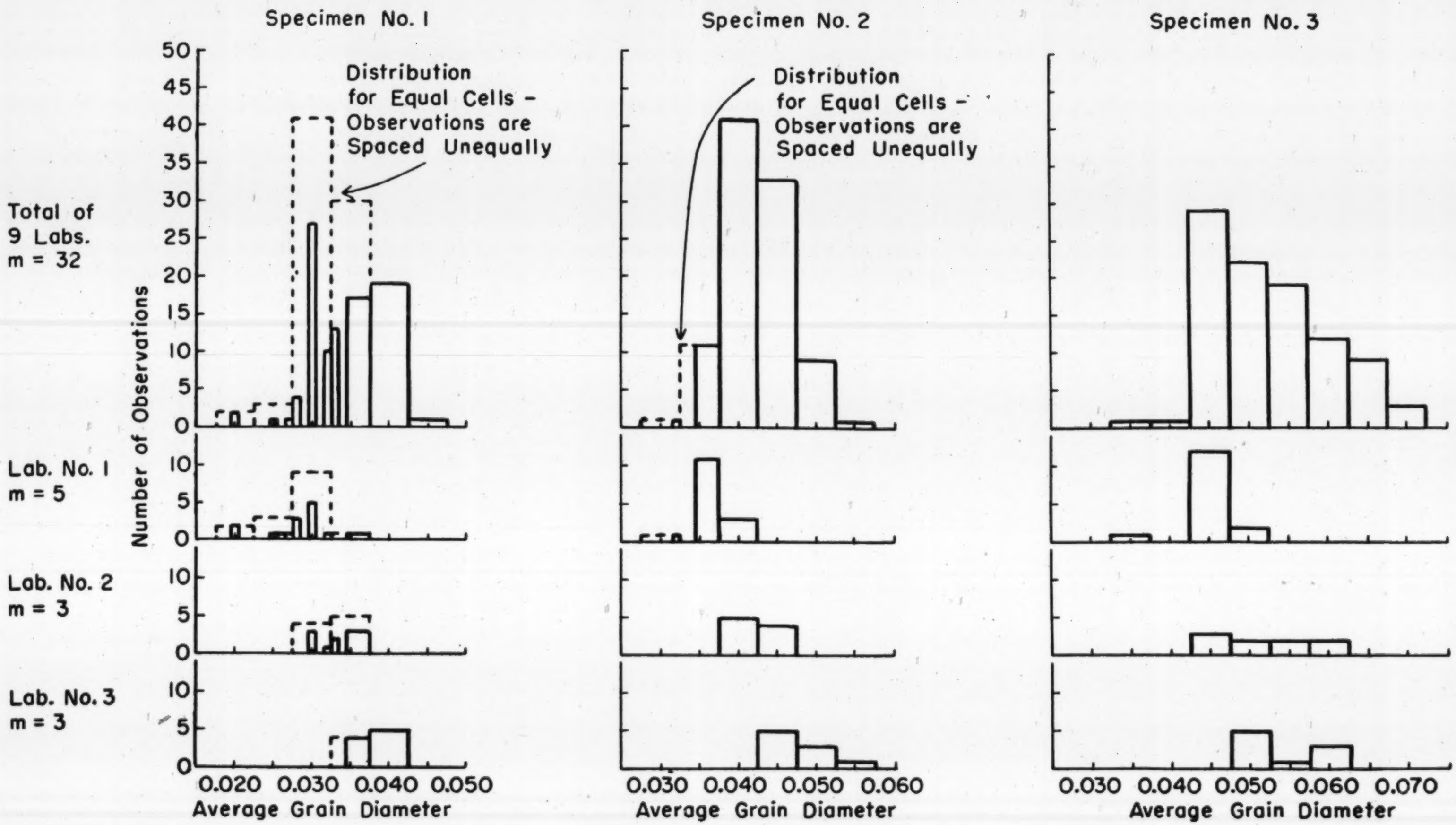
Results for Eight Specimens and for All Specimens Combined.

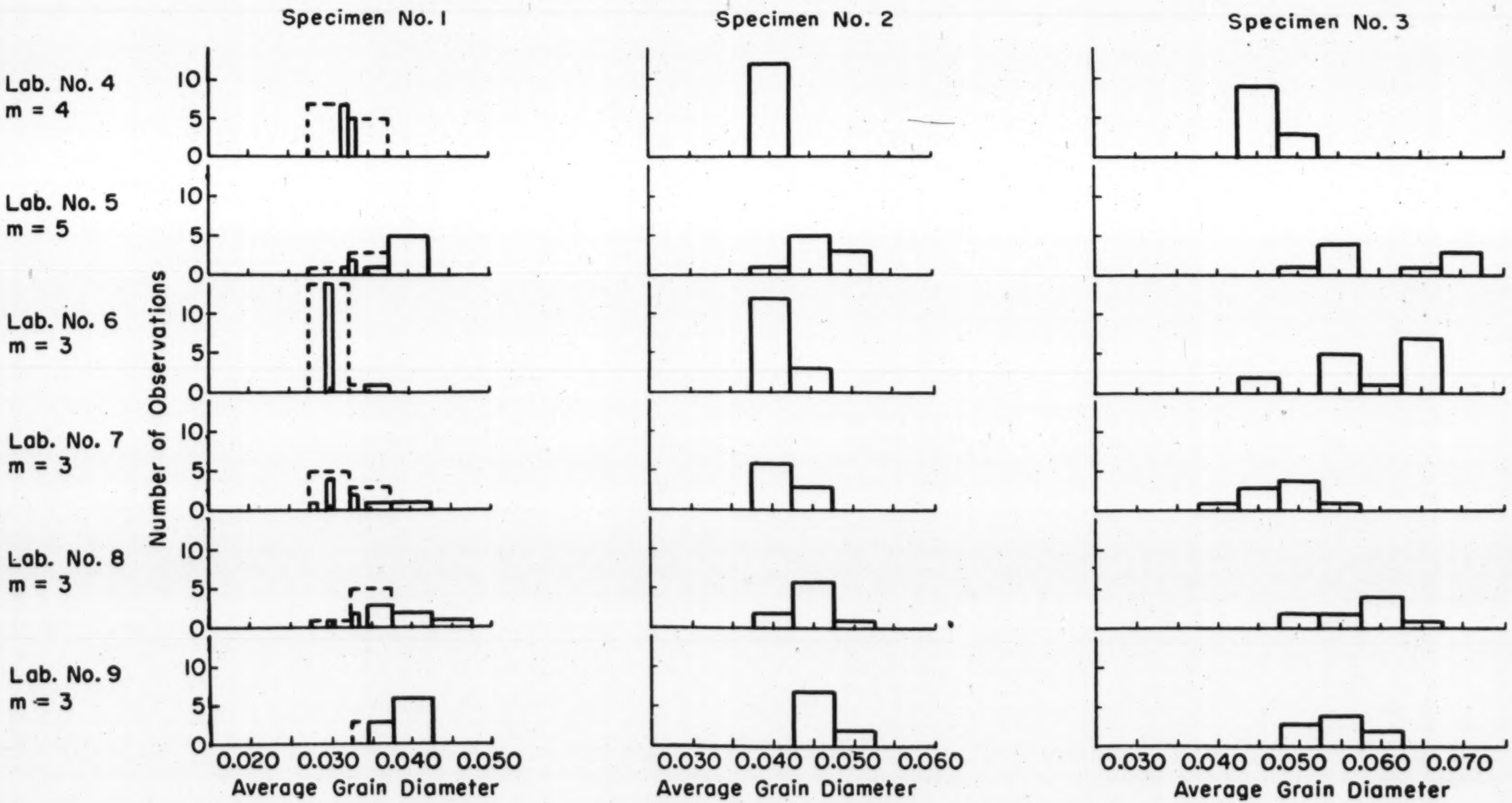
Average Grain Diameter.

Direct Comparison Method.

Operator	Specimen No. 1	Specimen No. 2	Specimen No. 3	Specimen No. 4	Specimen No. 5	Specimen No. 6	Specimen No. 7	Specimen No. 8	Sum of Ranks	Total Rank	Final Ranking		
											Rank	Operator	Laboratory
1A.......	2	5	9.5	13.5	15.5	15	10	8.5	79	8	1	1B	1
B.......	3	1	1	1	2.5	2	20.5	2	33	1	2	2A	4
C.......	1	2.5	5.5	5	5	3.5	4	29.5	56	3	3	1C	2
D.......	7.5	2.5	9.5	7	15.5	15	24	25.5	106.5	10	4	4A	7
E.......	7.5	4	5.5	7	9	7	1.5	20.5	62	6	5	4B	6
2A.......	21	10	5.5	2.5	1	1	10	3.5	54.5	2	6	1E	8
B.......	11	24.5	17.5	16	15.5	12	29	18.5	144	18	7	4D	3
C.......	20	16.5	24.5	24	15.5	27.5	16	22	166	24	8	1A	9
3A.......	23.5	24.5	15.5	10.5	24.5	18	10	12	138.5	16	9	4C	5
B.......	29.5	31.5	24.5	27	15.5	27.5	29	12	196.5	29	10	1D	
C.......	26.5	29.5	17.5	10.5	22	22	10	14.5	152.5	20	11	7A	
4A.......	14.5	10	5.5	10.5	6.5	3.5	1.5	5.5	57.5	4	12	6B	
B.......	14.5	10	5.5	2.5	2.5	7	10	8.5	60.5	5	13	6D	
C.......	19	10	13.5	13.5	11.5	18	10	8.5	104	9	14	9A	
D.......	17.5	10	5.5	4	9	5	6	5.5	62.5	7	15	6A	
5A.......	26.5	20	24.5	30	30	27.5	20.5	29.5	208.5	31	16	3A	
B......	17.5	24.5	20.5	19.5	30	22	20.5	16.5	171	25	17	7C	
C.......	29.5	31.5	32	32	27.5	32	27	31	242.5	32	18	2B	
6A.......	7.5	16.5	11.5	7	20	9.5	31	32	135	15	19	8A	
B.......	7.5	10	20.5	16	11.5	27.5	16	12	121	12	20	3C	
C.......	12	20	29	28.5	32	18	29	18.5	187	28	21	7B	
D.......	7.5	10	31	31	27.5	12	4	1	124	13	22	8C	
E.......	7.5	10	30	28.5	30	27.5	24	20.5	178	26	23	8B	
7A.......	4	10	11.5	16	6.5	22	16	25.5	111.5	11	24	2C	
B.......	23.5	16.5	2	24	9	20	32	25.5	152.5	21	25	5B	
C.......	14.5	20	15.5	24	15.5	12	24	16.5	142	17	26	6E	
8A.......	23.5	16.5	20.5	24	24.5	7	20.5	8.5	145	19	27	9B	
B.......	14.5	24.5	24.5	19.5	24.5	27.5	16	14.5	165.5	23	28	6C	
C.......	32	29.5	28	24	24.5	9.5	10	3.5	161	22	29	3B	
9A.......	29.5	24.5	13.5	10.5	4	15	4	25.5	126.5	14	30	9C	
B.......	29.5	24.5	20.5	19.5	20	27.5	16	25.5	183	27	31	5A	
C.......	23.5	28	27	19.5	20	27.5	26	25.5	197	30	32	5C	

NOTE.—1 denotes smallest value, . . . 32 denotes largest value.

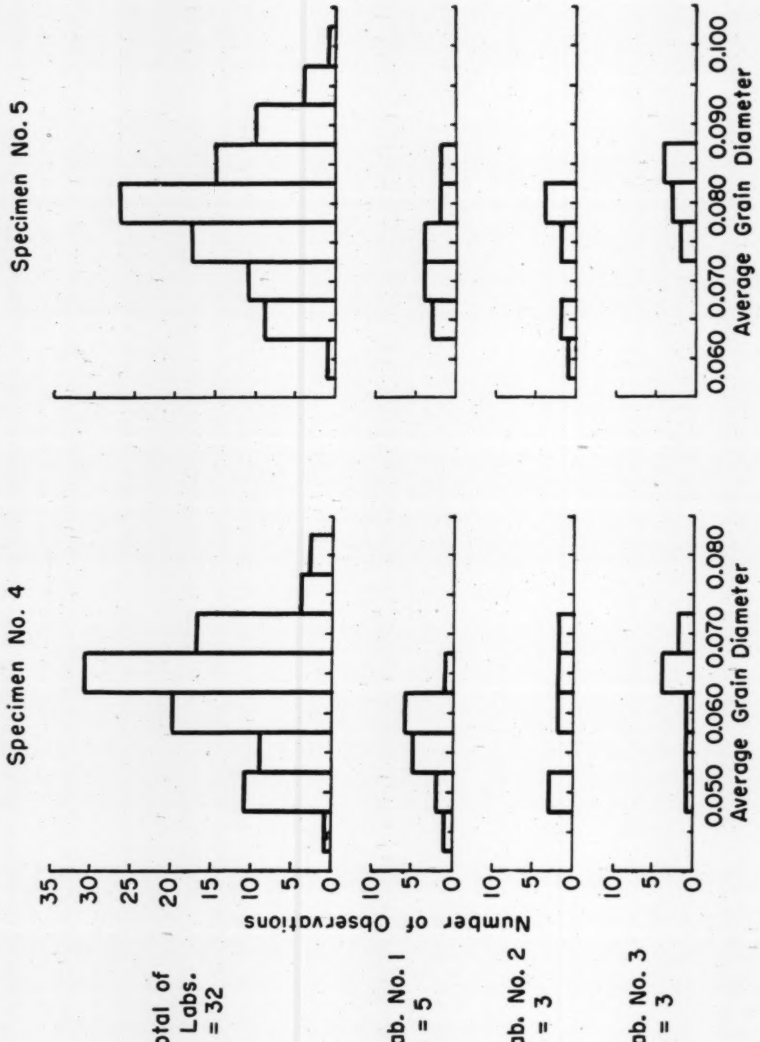

Specimen No. 1
Specimen No. 2
Specimen No. 3
Total of 9 Labs. m = 32
Lab. No. 1 m = 5
Lab. No. 2 m = 3
Lab. No. 3 m = 3
Number of Observations
0
5
10
15
20
25
30
35
40
45
50
Distribution for Equal Cells - Observations are Spaced Unequally
Distribution for Equal Cells - Observations are Spaced Unequally
0.020 0.030 0.040 0.050
0.030 0.040 0.050 0.060
0.030 0.040 0.050 0.060 0.070
Average Grain Diameter
Average Grain Diameter
Average Grain Diameter



Number of Observations per Operator = 3
Number of Operators = m

FIG. 3.—Distribution of Average Grain Diameter in Millimeters for Series *Y* Brass in the Direct Comparison Method. Eight specimens, nine laboratories.

(Continued on p. 194)


Specimen No. 4
Specimen No. 5
Total of 9 Labs. m = 32
Lab. No. 1 m = 5
Lab. No. 2 m = 3
Lab. No. 3 m = 3
Number of Observations
35 30 25 20 15 10 5 0
10 5 0
10 5 0
10 5 0
0.050 0.060 0.070 0.080
Average Grain Diameter
0.060 0.070 0.080 0.090 0.100
Average Grain Diameter

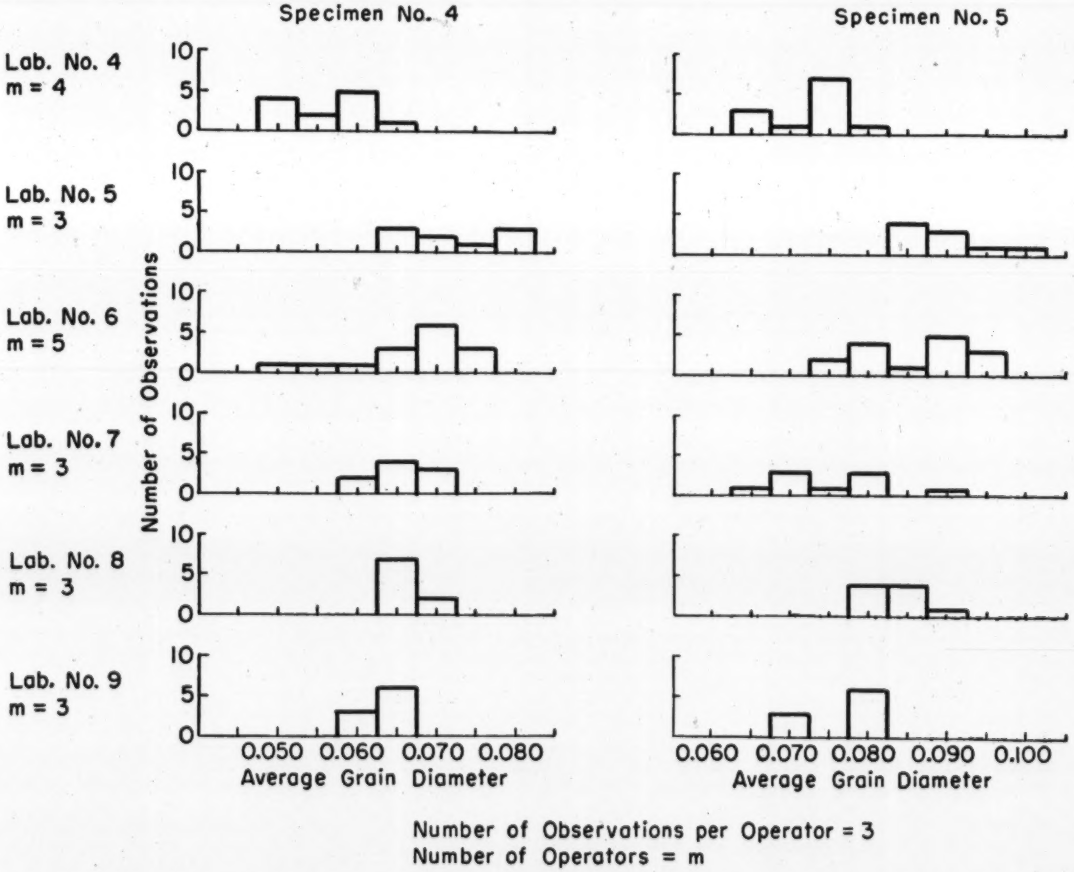
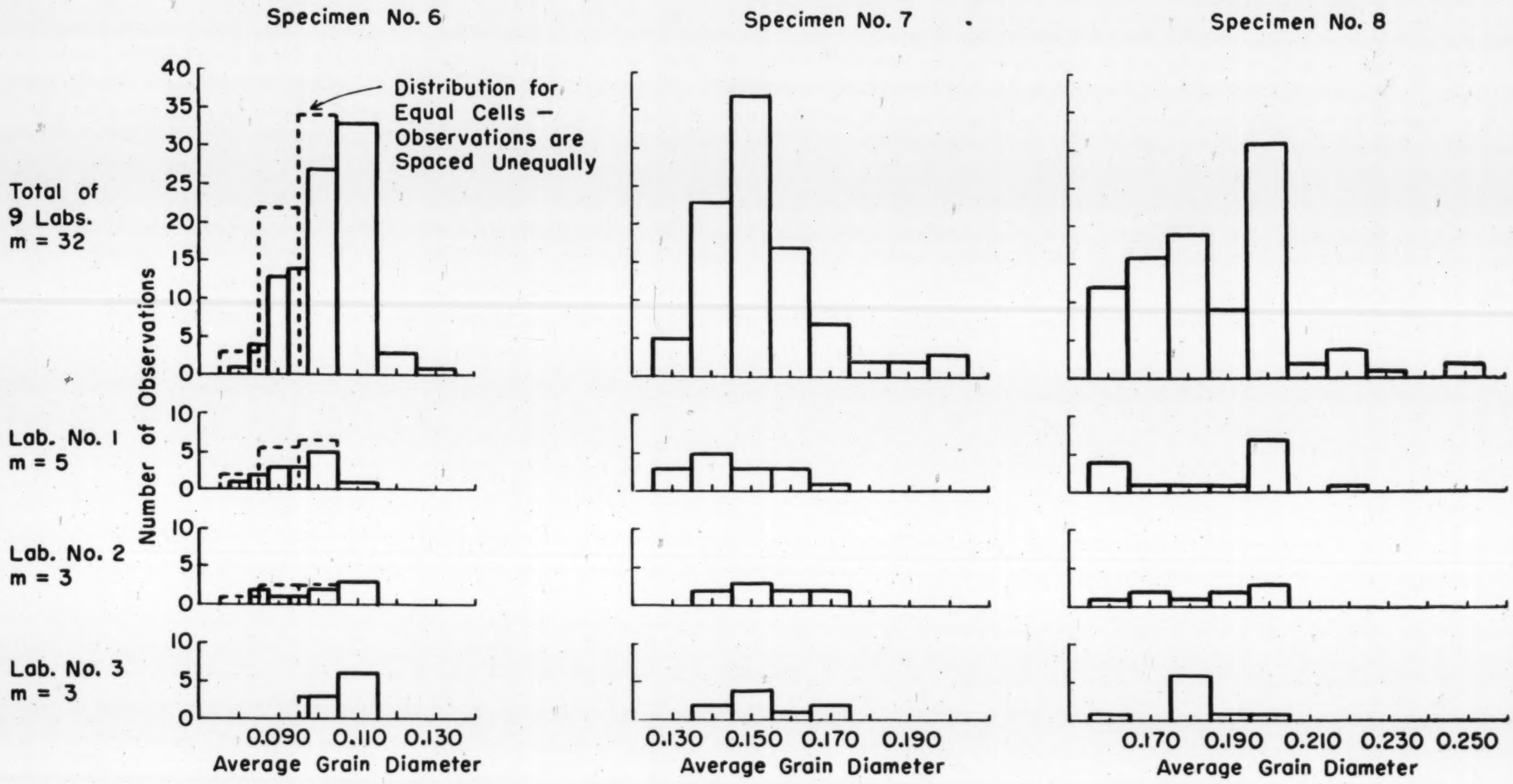


FIG. 3.—Distribution of Average Grain Diameter in Millimeters for Series *Y* Brass in the Direct Comparison Method. Eight specimens, nine laboratories. (*Continued*)

(Continued on p. 196)



Specimen No. 6
Specimen No. 7
Specimen No. 8
Distribution for Equal Cells — Observations are Spaced Unequally
Total of 9 Labs. m = 32
Lab. No. 1 m = 5
Lab. No. 2 m = 3
Lab. No. 3 m = 3
Number of Observations
40
35
30
25
20
15
10
5
0
10
5
0
0.090 0.110 0.130
0.130 0.150 0.170 0.190
0.170 0.190 0.210 0.230 0.250
Average Grain Diameter

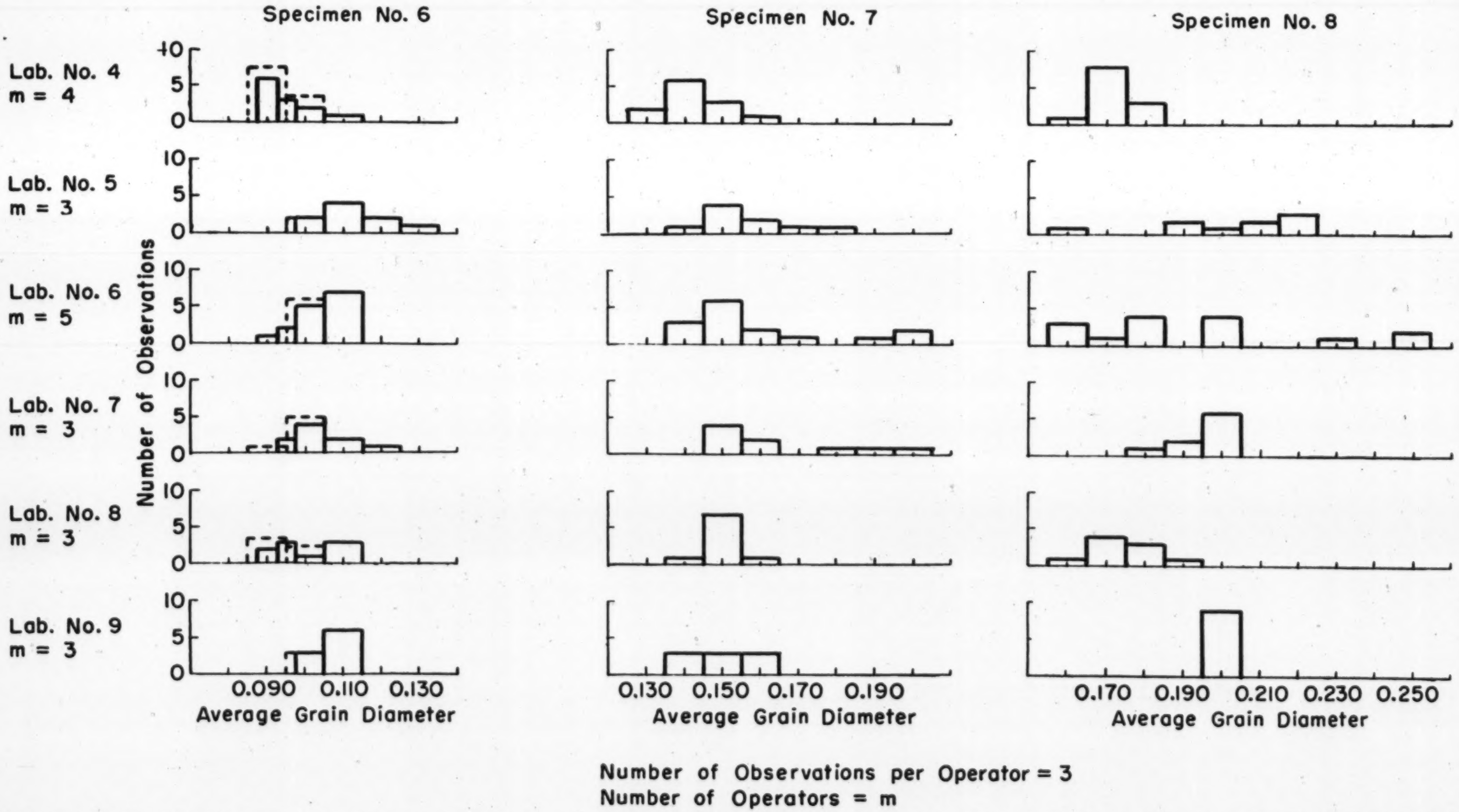


FIG. 3—Distribution of Average Grain Diameter in Millimeters for Series *Y* Brass in the Direct Comparison Method. Eight specimens, nine laboratories. (*Concluded*)

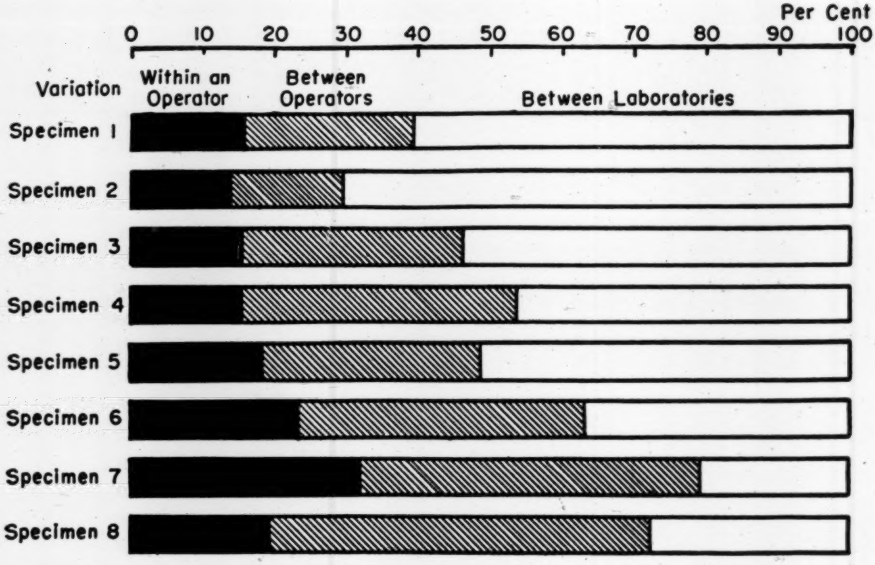


FIG. 4.—Contribution of Component Factors to Over-all Variation in the Direct Comparison Method. Average grain diameter; eight specimens, nine laboratories.

TABLE VIII.—SUMMARY OF ANALYSIS OF VARIANCE RESULTS.
Average Grain Diameter.
Direct Comparison Method.

	Variance Between Laboratories—Significant Difference, $P = 0.01$								Variance Within Laboratories—Significant Difference, $P = 0.05$							
Specimen...........	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8
All Nine Laboratories........	x	x	x	x	x	o	o	o	x	x	x	x	x	x	o	o

	Variance Between Operators at a Single Laboratory—Significant Difference, $P = 0.01$								Variance Within Individual Operators—Significant Difference, $P = 0.05$							
Specimen...........	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8
Laboratory:																
No. 1........	o	o	o	x	o	o	o	o	o	o	o	x	x	o	o	x
No. 2........	o	o	o	x	x	x	o	o	o	x	x	x	x	x	o	x
No. 3........	o	o	o	o	o	o	x	x	o	o	o	o	o	o	x	x
No. 4........	x	o	x	x	x	x	o	o	x	o	x	x	x	x	o	o
No. 5........	x	x	o	x	x	o	o	o	x	x	x	x	x	o	o	o
No. 6........	o	o	x	o	x	x	o	x	o	o	x	x	x	x	x	x
No. 7........	o	o	o	o	o	o	x	x	o	o	x	o	o	o	x	x
No. 8........	x	o	o	o	x	x	o	o	x	o	o	o	x	x	o	x
No. 9........	x	o	x	x	x	x	x	o	x	o	x	x	x	x	x	o

NOTE.
x denotes significant difference.
o denotes no significant difference.

TABLE IX.—VARIANCE VALUES UPON WHICH RESULTS IN TABLE VIII ARE BASED.

Average Grain Diameter.
Direct Comparison Method.

VARIANCE BETWEEN AND VARIANCE WITHIN LABORATORIES

	Specimen No. 1	Specimen No. 2	Specimen No. 3	Specimen No. 4	Specimen No. 5	Specimen No. 6	Specimen No. 7	Specimen No. 8
Variance between laboratories	0.000050	0.000054	0.000122	0.000103	0.000140	0.000126	0.000186	0.000415
Variance within laboratories	0.000007	0.000004	0.000024	0.000030	0.000029	0.000047	0.000149	0.000276

VARIANCE BETWEEN AND VARIANCE WITHIN INDIVIDUAL OPERATORS AT A SINGLE LABORATORY

Laboratory	Variance	Specimen No. 1	Specimen No. 2	Specimen No. 3	Specimen No. 4	Specimen No. 5	Specimen No. 6	Specimen No. 7	Specimen No. 8
No. 1	Between operators	0.000017	0.000009	0.000012	0.000077	0.000093	0.000090	0.000273	0.000917
	Within operator	0.000016	0.000004	0.000010	0.000007	0.000025	0.000048	0.000107	0.000187
No. 2	Between operators	0.000011	0.000019	0.000145	0.000240	0.000207	0.000419	0.000344	0.000719
	Within operator	0.000003	0.000003	0.000016	0.000011	0.000007	0.000014	0.000293	0.000075
No. 3	Between operators	0.000019	0.000019	0.000019	0.000069	0.000020	0.000033	0.000400	0.000011
	Within operator	0.000008	0.000011	0.000025	0.000036	0.000017	0.000022	0.000033	0.000144
No. 4	Between operators	0.000001	0	0.000019	0.000091	0.000081	0.000108	0.000119	0.000011
	Within operator	0.000000	0	0	0.000004	0.000004	0.000012	0.000058	0.000042
No. 5	Between operators	0.000044	0.000036	0.000203	0.000169	0.000003	0.000144	0.000069	0.000836
	Within operator	0.000003	0.000003	0.000019	0.000003	0.000036	0.000078	0.000142	0.000344
No. 6	Between operators	0.000002	0.000007	0.000143	0.000110	0.000169	0.000137	0.000950	0.002850
	Within operator	0.000004	0.000003	0.000015	0.000030	0.000003	0.000013	0.000220	0.000113
No. 7	Between operators	0.000024	0.000008	0.000053	0.000011	0.000019	0.000058	0.001378	0.000178
	Within operator	0.000010	0.000006	0.000008	0.000017	0.000072	0.000072	0.000044	0.000011
No. 8	Between operators	0.000073	0.000019	0.000019	0.000003	0	0.000253	0.000033	0.000211
	Within operator	0.000004	0.000006	0.000028	0.000006	0.000017	0.000011	0.000022	0.000033
No. 9	Between operators	0.000025	0.000011	0.000053	0.000025	0.000100	0.000100	0.000300	0
	Within operator	0	0.000003	0.000003	0	0	0	0	0

TABLE X.—OVER-ALL VARIATION FOR ALL NINE LABORATORIES.

Average Grain Diameter.

Direct Comparison Method.

Variation	Standard Deviation, σ	Variance, v	Contribution to Total Deviation, per cent	Standard Deviation, σ	Variance, v	Contribution to Total Deviation, per cent
	Specimen No. 1			Specimen No. 2		
Within single operator	0.0018042	0.000003	15.8	0.001634	0.000003	13.9
Between operators	0.0021902	0.000005	23.4	0.001737	0.000003	15.7
Between laboratories	0.0035341	0.000012	60.8	0.003676	0.000014	70.4
Total	0.00454	0.000021	100.0	0.004380	0.000019	100.0
	Specimen No. 3			Specimen No. 4		
Within single operator	0.002972	0.000009	15.6	0.002940	0.000009	15.5
Between operators	0.004163	0.000017	30.5	0.004628	0.000021	38.4
Between laboratories	0.005529	0.000031	53.9	0.005072	0.000026	46.1
Total	0.007532	0.000057	100.0	0.007469	0.000056	100.0
	Specimen No. 5			Specimen No. 6		
Within single operator	0.003544	0.000013	18.4	0.004449	0.000020	23.3
Between operators	0.004552	0.000021	30.4	0.005818	0.000034	39.8
Between laboratories	0.005908	0.000035	51.2	0.005605	0.000031	36.9
Total	0.008257	0.000068	100.0	0.009223	0.000085	100.0
	Specimen No. 7			Specimen No. 8		
Within single operator	0.008504	0.000072	32.0	0.008529	0.000073	19.4
Between operators	0.010359	0.000107	47.4	0.014072	0.000198	52.9
Between laboratories	0.006828	0.000047	20.6	0.010183	0.000104	27.7
Total	0.015041	0.000226	100.0	0.019351	0.000374	100.0

TABLE XI.—APPARATUS USED IN DETERMINATIONS OF GRAIN SIZE BY TRANSPARENCY METHOD.

Laboratory	Objective	Ocular	Bellows Extension	Source of Illumination	Diameter of Projected Circle	Additional Information
No. 1	Achromatic 18 n.a.—0.30	8 ×		Carbon arc	85 mm	Viewing box with standard transparencies made from ASTM negatives
No. 2	22.7 mm	12.5 ×	8⅜ in. to screen	Carbon arc	2½ by 3¼ in.	Grain size comparator with transparencies

2. Variation between operators, and
3. Variation between laboratories,

to the total variation for each specimen for results obtained by the direct comparison method. Figure 4 and Table X give a summary of these results.

It is apparent that for specimens Nos. 1 to 5, inclusive, the variation between laboratories is the largest contributing factor to the over-all variation. For specimens Nos. 6, 7, and 8 the variation between operators is the largest contributing factor to the over-all variation.

APPENDIX C

STATISTICAL ANALYSIS OF 1940 RESULTS FOR TRANSPARENCY METHOD

Scope:

This memorandum presents an analysis of the data obtained for eight of the ten series *Y* brass specimens by the transparency method for the determination of grain size by laboratories Nos. 1 and 2. This progress report gives a statistical analysis and summary of these results. Results for specimens Nos. 9 and 10 having large grain sizes are omitted in accordance with the recommendations of the subcommittee.

Nature of Data:

The section on Nature of Data in Appendix B describes the procedure, instructions, and forms used in obtaining the test results. Data based on the transparency method were submitted by only two laboratories. Table XI presents a description of the apparatus used by these two laboratories.

Control Analysis of Results:

Following the steps outlined on Form No. 2, "Summary Sheet," submitted by each of the two laboratories, average and standard deviation values were computed for the determinations of grain size by each operator, and for all operators combined, for each of the specimens. Using the average value for each operator, the variation between operators at a single laboratory was determined as a standard deviation (σ), the root mean square deviation for averages. Table XII summarizes these results. This table also includes average values of the standard deviation between operators, used to determine control limits. These results are tabulated for each of the first eight specimens. All values outside the 3 σ control limits are designated as a (above) and b (below).

Table XIII lists the average value for each specimen determined at each of the two laboratories and the standard deviation values used for control analyses. No one of these average values was found to be outside its 3 σ control limits. These results, together with those given in Table XII, indicate in tabular form similar results to those indicated by control charts for average values.

Table XIV presents a summary of the consistency of the results for the two laboratories compared with the over-all results. These findings are presented in terms of the number and percentage of values outside the 3 σ control limits. Since only two laboratories submitted data for the transparency method, these results reflect only the degree of control that was maintained by the eight operators at these laboratories.

Analysis of Results by Ranking:

The average and standard deviation values obtained in this study for each operator may be simplified by means of ordering the operators. This is termed the method of ranking. Since true values are not known for the average grain size of each specimen, rank 1 is assigned arbitrarily to the smallest value and rank 8 to the largest value determined by the eight operators. Similarly rank 1 is assigned to the smallest standard deviation value and rank 8 to the largest standard deviation value, measuring the variation between repetitive determinations by the same operator (designated herein as the variation within an operator, σ_w). Table XV presents a summary of these values and ranks the two laboratories with respect to

TABLE XII.—SUMMARY OF AVERAGE AND STANDARD DEVIATION VALUES FOR EACH SPECIMEN BY LABORATORIES AND BY OPERATORS.

Average Grain Diameter in Millimeters.

Transparency Method.

Laboratory	Operator A		Operator B		Operator C		Operator D		Operator E		All Operators			
	$\overline{X}$	σ_w	$\overline{X}$	σ_w	$\overline{X}$	σ_w	$\overline{X}$	σ_w	$\overline{X}$	σ_w	$\overline{X}$	σ_o	$\sigma_{\overline{X}}$	$\bar{\sigma}_w$
SPECIMEN No. 1														
No. 1........	0.0293	0.00095	0.0293	0.00095	0.0313	0.00263	0.0330	0.00058	0.0293	0.00095	0.0305	0.00206	0.00150	0.00122
No. 2........	0.0323	0.00154	0.0293	0.00189	0.0300	0.00163					0.0306	0.00195	0.00129	0.00169
SPECIMEN No. 2														
No. 1........	0.0433	0.00236	0.0400	0	0.0417	0.00236	0.0417	0.00236	0.0383	0.00236	0.0410	0.00271	0.00171	0.00189
No. 2........	0.0367	0.00235	0.0400	0	0.0417	0.00235					0.0394	0.00284	0.00247	0.00157
SPECIMEN No. 3														
No. 1........	0.0567	0.00235	0.0433	0.00236	0.0500	0.00408	0.0533	0.00850	0.0467	0.00623	0.0500	0.00707	0.00471	0.00470
No. 2........	0.0417	0.00236	0.0450	0.00163	0.0500	0.00707					0.0456	0.00558	0.00350	0.00334
SPECIMEN No. 4														
No. 1........	0.0550	0.00816	0.0467	0.00235	0.0600	0.00408	0.0617	0.00943	0.0600	0.00707	0.0567	0.00869	0.00548	0.00622
No. 2........	0.0483	0.00236	0.0533	0.00236	0.0550	0.00408					0.0522	0.00485	0.00377	0.00293

						SPECIMEN No. 5							
No. 1	0.0800	0.00408	0.0617[b]	0.00236	0.0733	0.00471	0.0800	0.00408	0.0717	0.00236	0.0733	0.00767	0.00675	0.00352
No. 2	0.0633[b]	0.00313	0.0733	0.00236	0.0800	0.00408					0.0722	0.00749	0.00685	0.00319
						SPECIMEN No. 6							
No. 1	0.103	0.00471	0.102	0.00624	0.108	0.0103	0.113	0.0125	0.0983	0.00236	0.105	0.00966	0.00527	0.00722
No. 2	0.0867[b]	0.00234	0.0967	0.00471	0.0967	0.00234					0.0933	0.00577	0.00486	0.00308
						SPECIMEN No. 7							
No. 1	0.165	0.0108	0.210[a]	0.00816	0.157	0.00471	0.167	0.0125	0.163	0.0125	0.172	0.0217	0.0191	0.00974
No. 2	0.147	0.00470	0.160	0.00233	0.153	0.00570					0.153	0.00667	0.00614	0.00424
						SPECIMEN No. 8							
No. 1	0.183	0.0170	0.223[a]	0.0205	0.213	0.00471	0.190	0.0141	0.197	0.0125	0.201	0.0209	0.0148	0.0138
No. 2	0.167	0.00459	0.183	0.00471	0.173	0.00581					0.174	0.00831	0.00757	0.00483

NOTES AND DEFINITIONS OF SYMBOLS:

Nine laboratories involved in complete study designated by Nos. 1 to 9, inclusive.

Only laboratories Nos. 1 and 2 obtained results for the transparency method.

Operators at each laboratory designated by letters A, B, C, D, and E.

$\overline{X}$ = average arithmetic mean.

σ_w = variation within group of observations for a single operator; standard deviation within group.

$\bar{\sigma}_w$ = average standard deviation within group.

σ_o = over-all variation within a single laboratory; over-all standard deviation.

$\sigma_{\overline{X}}$ = variation between average determinations of operators in a single laboratory; standard deviation between operators (designated as σ_b hereafter).

[a] Average or standard deviation significantly greater than expected value for all laboratories combined; above larger 3 σ control limit.

[b] Average or standard deviation significantly less than expected value for all laboratories combined; below smaller 3 σ control limit.

TABLE XIII.—SUMMARY OF AVERAGE AND STANDARD DEVIATION VALUES USED IN CONTROL ANALYSIS FOR EACH SPECIMEN BY LABORATORIES.

Average Grain Diameter in Millimeters.

Transparency Method.

Laboratory	Number of Operators	Number of Observations	Average, $\bar{X}$	Standard Deviation Within Individual Operators		Standard Deviation Between Individual Operators		Over-all Standard Deviation	
				Average, $\bar{\sigma}_w$	Corrected, σ'_w	σ_b	Corrected, σ'_b	σ_o	Corrected, σ'_o
SPECIMEN No. 1									
No. 1.....	5	15	0.0305	0.00121		0.00150		0.00206	
No. 2.....	3	9	0.0306	0.00169		0.00129		0.00195	
	8	24	0.0305	0.00139	0.00192	0.00140	0.00178	0.00201	0.00216
SPECIMEN No. 2									
No. 1.....	5	15	0.0410	0.00189		0.00171		0.00271	
No. 2.....	3	9	0.0394	0.00157		0.00247		0.00284	
	8	24	0.0404	0.00177	0.00244	0.00209	0.00272	0.00278	0.00276
SPECIMEN No. 3									
No. 1.....	5	15	0.0500	0.00470		0.00471		0.00707	
No. 2.....	3	9	0.0460	0.00334		0.00350		0.00537	
	8	24	0.0485	0.00419	0.00579	0.00411	0.00522	0.00622	0.00686
SPECIMEN No. 4									
No. 1.....	5	15	0.0567	0.00622		0.00548		0.00869	
No. 2.....	3	9	0.0522	0.00293		0.00377		0.00485	
	8	24	0.0550	0.00499	0.00689	0.00463	0.00586	0.00677	0.00771
SPECIMEN No. 5									
No. 1.....	5	15	0.0733	0.00386		0.00675		0.00767	
No. 2.....	3	9	0.0722	0.00319		0.00684		0.00749	
	8	24	0.0729	0.00340	0.00469	0.00680	0.00874	0.00758	0.00807
SPECIMEN No. 6									
No. 1.....	5	15	0.105	0.00722		0.00527		0.00966	
No. 2.....	3	9	0.093	0.00308		0.00486		0.00568	
	8	24	0.101	0.00567	0.00783	0.00506	0.00649	0.00767	0.00869
SPECIMEN No. 7									
No. 1.....	5	15	0.172	0.00973		0.0191		0.0217	
No. 2.....	3	9	0.153	0.00424		0.00614		0.00667	
	8	24	0.165	0.00768	0.0106	0.0126	0.0156	0.0141	0.0170
SPECIMEN No. 8									
No. 1.....	5	15	0.201	0.0138		0.01480		0.02090	
No. 2.....	3	9	0.174	0.00483		0.00757		0.00831	
	8	24	0.191	0.0104	0.0144	0.0112	0.0140	0.0146	0.0172

TABLE XIV.—NUMBER AND PERCENTAGE OF AVERAGE VALUES WITHIN CONTROL LIMITS.

Eight Specimens, Two Laboratories.
Average Grain Diameter.
Transparency Method.

Laboratory	Averages for Individual Operators				
	Number of Operators	Above[a]	Below[b]	Within Control Limits	
				No.	Per cent
No. 1.....	5	2	1	37	92.5
No. 2.....	3	0	2	23	91.7
	8	2	3	60	92.1

[a] Denotes that average value is greater than upper 3 σ control limits.

[b] Denotes that average value is less than lower 3 σ control limits.

these two statistics. Where average or standard deviation values were the same for several operators, the average of the ranks involved were assigned to each operator.

Analysis of Distributions and Variations of Results:

Distributions of the actual observations for each of the two laboratories and for the two laboratories combined for each of the eight specimens are presented in Fig. 5. For all specimens the charts give observations for the actual cell widths required to be used under the instructions noted in Nature of Data, Appendix B. Distributions using equal cell widths are given by the dotted lines for specimens Nos. 1 and 6 so that it is possible to visualize the nature of the distributions. These charts indicate

TABLE XV.—RANKING OF OPERATORS AND LABORATORIES WITH RESPECT TO AVERAGE AND STANDARD DEVIATION VALUES OBTAINED FOR EACH OPERATOR.

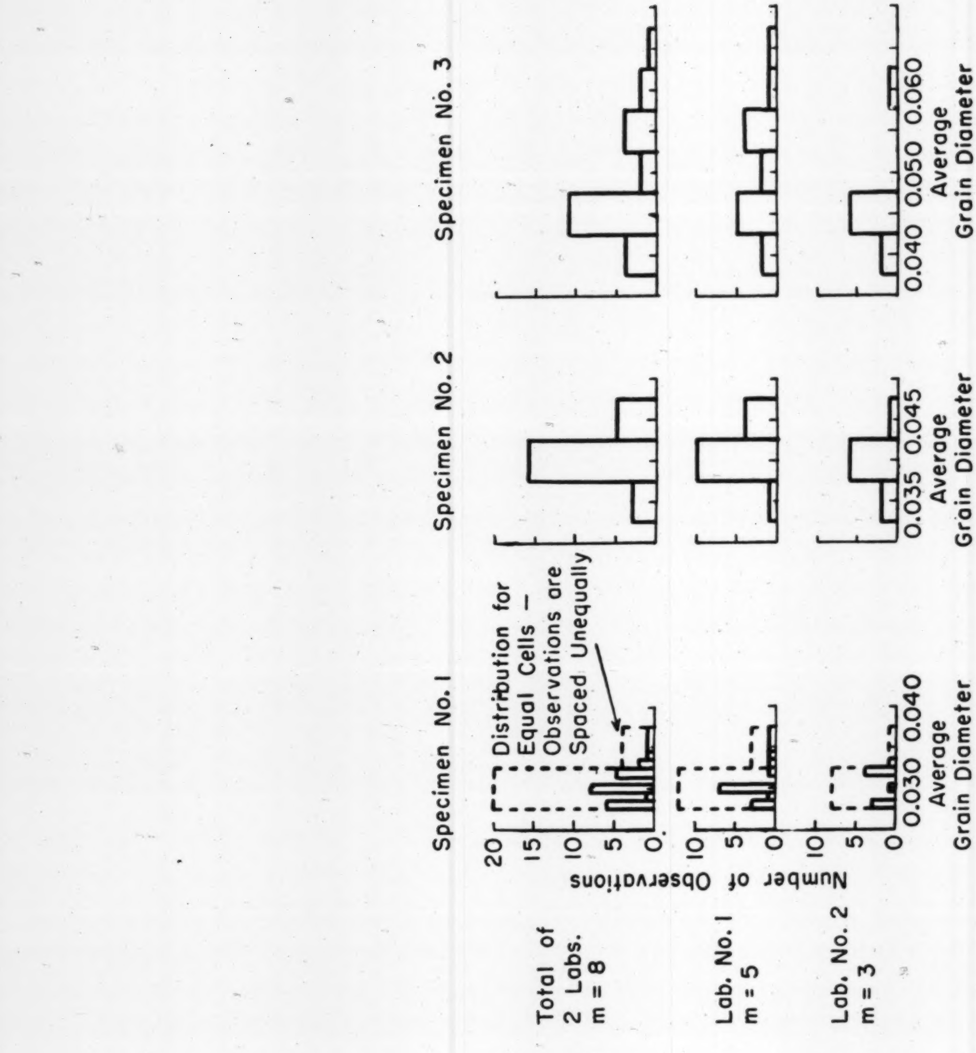
Results for Eight Specimens and for All Eight Specimens Combined

Average Grain Diameter.

Transparency Method.

Operator	Specimen No. 1	Specimen No. 2	Specimen No. 3	Specimen No. 4	Specimen No. 5	Specimen No. 6	Specimen No. 7	Specimen No. 8	Sum of Ranks	Total Rank	Final Ranking		
											Rank	Operator	Laboratory
AVERAGES, $\bar{X}$													
1A........	2.5	8	8	4.5	7	6	6	3.5	45.5	6.5	1	2A	2
B........	2.5	3.5	2	1	1	5	8	8	31	3	2	2B	1
C........	6	6	5.5	6.5	4.5	7	3	7	45.5	6.5	3	1B	
D........	8	6	7	8	7	8	7	5	56	8	4	1E	
E........	2.5	2	4	6.5	3	4	5	6	33	4	5	2C	
2A........	7	1	1	2	2	1	1	1	11	1	6.5	1A	
B........	2.5	3.5	3	3	4.5	2.5	4	3.5	26.5	2	6.5	1C	
C........	5	6	5.5	4.5	7	2.5	2	2	34.5	5	8	1D	
STANDARD DEVIATIONS, σ_w													
1A........	3	6.5	2	7	6	4.5	6	7	42	6	1	2B	2
B........	3	1.5	3.5	1	2	6	5	8	30	3	2	2A	1
C........	8	6.5	5	4.5	8	7	3	2.5	44.5	7	3	1B	
D........	1	6.5	8	8	6	8	7.5	6	51	8	4	2C	
E........	3	6.5	6	6	2	3	7.5	5	39	5	5	1E	
2A........	5	3.5	3.5	2.5	4	1.5	2	1	23	2	6	1A	
B........	7	1.5	1	2.5	2	4.5	1	2.5	22	1	7	1C	
C........	6	3.5	7	4.5	6	1.5	4	4	36.5	4	8	1D	

NOTE.—The results in the table indicate that operators 2A, 2B, and 1B obtained consistently smaller values for grain size diameter and also had smaller variations between repeat measurements than did the other five operators.


Specimen No. 1
Specimen No. 2
Specimen No. 3
Total of 2 Labs. m = 8
Lab. No. 1 m = 5
Lab. No. 2 m = 3
Number of Observations
20
15
10
5
0
10
5
0
10
5
0
Distribution for Equal Cells — Observations are Spaced Unequally
0.030 0.040
Average Grain Diameter
0.035 0.045
Average Grain Diameter
0.040 0.050 0.060
Average Grain Diameter

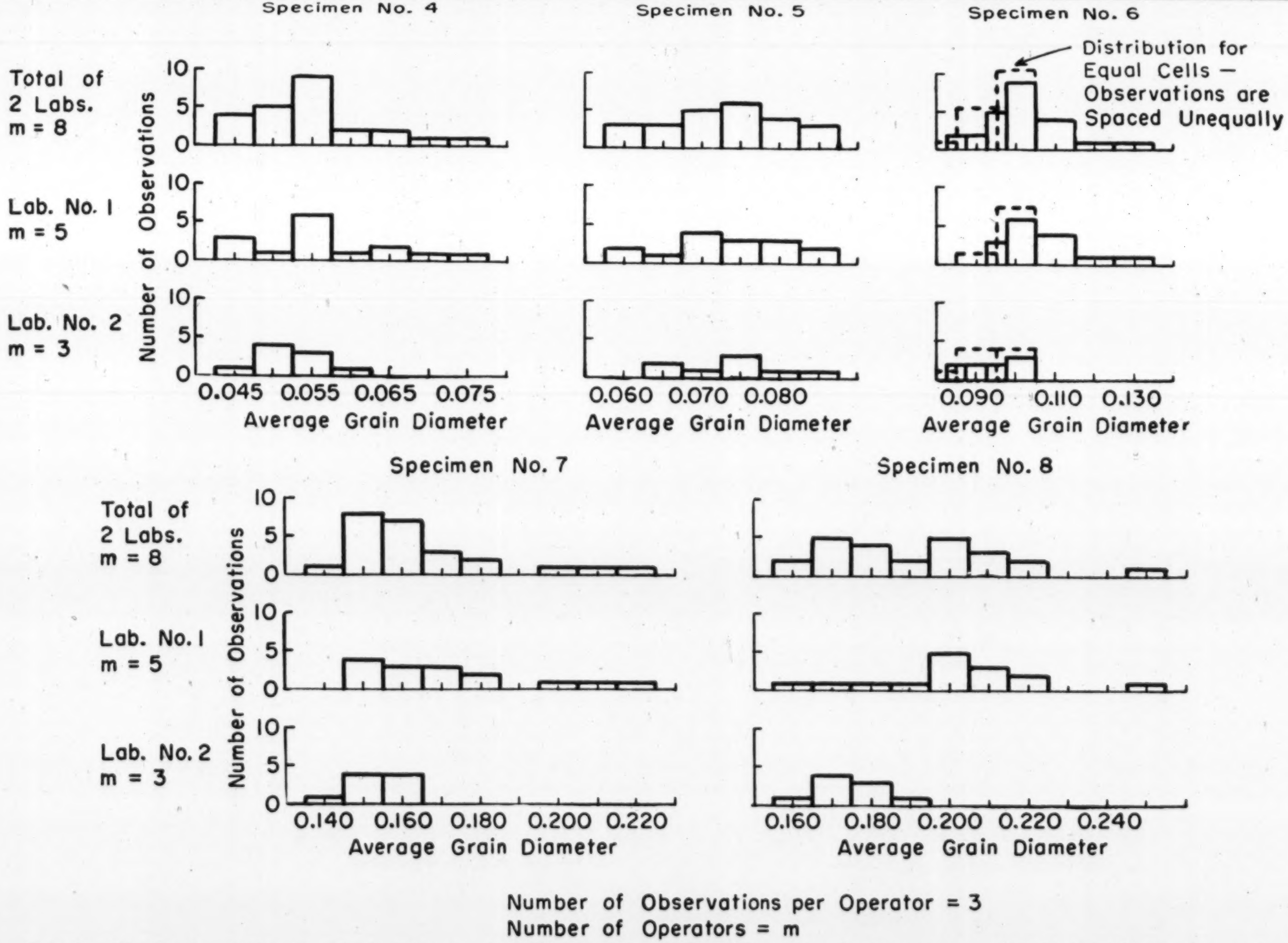


FIG. 5.—Distribution of Average Grain Diameter in Millimeters for Series *Y* Brass in the Transparency Method. Eight specimens, two laboratories.

TABLE XVI.—SUMMARY OF ANALYSIS OF VARIANCE RESULTS.

Average Grain Diameter.

Transparency Method.

	Variance Between Operators at a Single Laboratory—Significant Difference, $P = 0.01$								Variance Within Individual Operators at a Single Laboratory—Significant Difference, $P = 0.05$							
Specimen..........	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8
Laboratory:																
No. 1........	o	o	o	o	x	o	x	o	o	o	o	o	x	o	x	o
No. 2........	o	o	o	o	x	o	o	o	o	o	o	o	x	x	x	x

NOTE.
x denotes significant difference.
o denotes no significant difference.

TABLE XVII.—VARIANCE VALUES UPON WHICH RESULTS IN TABLE XVI ARE BASED.

Transparency Method.

Laboratory	Variance	Specimen No. 1	Specimen No. 2	Specimen No. 3	Specimen No. 4	Specimen No. 5	Specimen No. 6	Specimen No. 7	Specimen No. 8
No. 1....	Between operators	0.000008	0.000011	0.000083	0.000112	0.000171	0.000104	0.001373	0.000827
	Within operator	0.000003	0.000007	0.000042	0.000068	0.000020	0.000098	0.000155	0.000327
No. 2....	Between operators	0.000007	0.000019	0.000053	0.000036	0.000211	0.000100	0.000133	0.000211
	Within operator	0.000003	0.000006	0.000029	0.000023	0.000014	0.000017	0.000022	0.000033

TABLE XVIII.—OVER-ALL VARIATION FOR EACH LABORATORY SHOWING CONTRIBUTION OF VARIATION WITHIN AND VARIATION BETWEEN OPERATORS TO OVER-ALL VARIATION.

Average Grain Diameter.

Transparency Method.

Variation	Standard Deviation, σ	Variance, v	Contribution to Total Variation, per cent	Standard Deviation, σ	Variance, v	Contribution To Total Variation, per cent
	SPECIMEN No. 1			SPECIMEN No. 2		
	LABORATORY No. 1					
Within single operator	0.00167	0.0000027889	46.8	0.00261	0.0000068121	62.3
Between operators....	0.00178	0.0000031684	53.2	0.00203	0.0000041209	37.7
Total.............	0.00244	0.0000059573	100.0	0.00330	0.0000109330	100.0

TABLE XVIII.—*Concluded.*

Variation	Standard Deviation, σ	Variance, v	Contribution to Total Variation, per cent	Standard Deviation, σ	Variance, v	Contribution To Total Variation, per cent
	LABORATORY NO. 2					
Within single operator	0.00234	0.0000054756	63.3	0.00217	0.0000047089	28.8
Between operators....	0.00178	0.0000031684	36.7	0.00341	0.0000116281	71.2
Total............	0.00294	0.0000086440	100.0	0.00404	0.0000163370	100.0
	SPECIMEN NO. 3			SPECIMEN NO. 4		
	LABORATORY NO. 1					
Within single operator	0.00650	0.0000422500	57.4	0.00860	0.0000739600	63.5
Between operators....	0.00560	0.0000313600	42.6	0.00652	0.0000425104	36.5
Total............	0.00858	0.0000736100	100.0	0.01079	0.0001164704	100.0
	LABORATORY NO. 2					
Within single operator	0.00462	0.0000213444	47.7	0.00405	0.0000164025	37.7
Between operators....	0.00484	0.0000234256	52.3	0.00521	0.0000271441	62.3
Total............	0.00669	0.0000447700	100.0	0.00660	0.0000435466	100.0
	SPECIMEN NO. 5			SPECIMEN NO. 6		
	LABORATORY NO. 1					
Within single operator	0.00533	0.0000284089	30.6	0.00998	0.0000996004	71.7
Between operators....	0.00803	0.0000644809	69.4	0.00627	0.0000393129	28.3
Total............	0.00964	0.0000928898	100.0	0.01179	0.0001389133	100.0
	LABORATORY NO. 2					
Within single operator	0.00441	0.0000194481	17.9	0.00426	0.0000181476	28.7
Between operators....	0.00945	0.0000893025	82.1	0.00672	0.0000451584	71.3
Total............	0.01043	0.0001087506	100.0	0.00796	0.0000633060	100.0
	SPECIMEN NO. 7			SPECIMEN NO. 8		
	LABORATORY NO. 1					
Within single operator	0.01345	0.0001809025	26.0	0.01907	0.0003636649	54.0
Between operators....	0.02272	0.0005161984	74.0	0.01760	0.0003097600	46.0
Total............	0.02640	0.0006971009	100.0	0.02595	0.0006734249	100.0
	LABORATORY NO. 2					
Within single operator	0.00586	0.0000343396	32.3	0.00668	0.0000446224	29.0
Between operators....	0.00849	0.0000720801	67.7	0.01046	0.0001094116	71.0
Total............	0.01032	0.0001064197	100.0	0.01241	0.0001540340	100.0

TABLE XIX.—SUMMARY OF AVERAGE AND STANDARD DEVIATION VALUES FOR EACH SPECIMEN BY LABORATORIES AND BY OPERATORS.

Average Grain Diameter in Millimeters.

Intercept Method.

Laboratory	Operator A		Operator B		Operator C		Operator D		Operator E		All Operators			
	$\overline{X}$	σ_w	$\overline{X}$	σ_w	$\overline{X}$	σ_w	$\overline{X}$	σ_w	$\overline{X}$	σ_w	$\overline{X}$	σ_o	$\sigma_{\overline{X}}$	$\overline{\sigma}_w$
SPECIMEN No. 1														
No. 1	0.0240	...	...	...	...	...	...	...	...	...	0.0240	...	...	...
No. 6	0.0493	0.00478	0.0347	0.00125	0.0367	0.00450	0.0380	0.00327	0.0510	0.00163	0.0419	0.00721	0.00683	0.00309
No. 9	0.0393	0.000943	0.0387	0.000943	0.0367	0.000943					0.0382	0.00147	0.00113	0.000943
SPECIMEN No. 2														
No. 1	0.0410	...	...	...	...	...	...	...	...	...	0.0410	...	...	...
No. 6	0.0573	0.00741	0.0433	0.00125	0.0483	0.000471	0.0470	0.00490	0.0597	0.000471	0.0511	0.00746	0.00628	0.00290
No. 9	0.0490	0.00141	0.0480	0.00141	0.0500	0					0.0490	0.00141	0.000816	0.000940
SPECIMEN No. 3														
No. 1	0.0440	...	...	...	...	...	...	...	...	...	0.0440	...	...	...
No. 6	0.0703	0.00189	0.0570	0.00455	0.0553	0.00249	0.0583	0.00262	0.0700	0.00432	0.0622	0.00738	0.00657	0.00317
No. 9	0.0540	0.00141	0.0587	0.00189	0.0573	0.00189					0.0567	0.00262	0.00196	0.00173
SPECIMEN No. 4														
No. 1	0.0520	...	...	...	...	...	...	...	...	...	0.0520	...	...	...
No. 6	0.0820	0.00245	0.0623	0.00573	0.0570	0.00141	0.0643	0.00801	0.0860	0.00589	0.0703	0.0126	0.0115	0.00470
No. 9	0.0603	0.00368	0.0633	0.00236	0.0683	0.00236					0.0640	0.00437	0.00330	0.00280
SPECIMEN No. 5														
No. 1	0.0620	...	...	...	...	...	...	...	...	...	0.0620	...	...	...
No. 6	0.0897	0.00771	0.0770	0.00374	0.0673	0.00236	0.0700	0.00432	0.1100	0.00283	0.0828	0.0163	0.0156	0.00419
No. 9	0.0773	0.00189	0.0760	0	0.0827	0.00189					0.0787	0.00327	0.00288	0.00126

Specimen No. 6

No. 1........	0.0880	...	...	...	...	...	...	...	...	...	0.0880	...	...	...
No. 6........	0.1057	0.0102	0.0997	0.00189	0.0997	0.00189	0.0780	0.00572	0.1483	0.0104	0.1063	0.0109	0.0230	0.00602
No. 9........	0.1067	0.00236	0.1133	0.00471	0.1067	0.00236					0.1089	0.00431	0.00314	0.00314

Specimen No. 7

No. 1........	0.1300	...	...	...	...	...	...	...	...	...	0.1300	...	...	...
No. 6........	0.1697	0.0172	0.1393	0.00896	0.1530	0.0141	0.1407	0.0160	0.1823	0.00754	0.1570	0.0214	0.0167	0.0128
No. 9........	0.1500	0	0.1750	0	0.1680	0					0.1643	0.0105	0.0105	0

Specimen No. 8

No. 1........	0.1750	...	...	...	...	...	...	...	...	...	0.1750	...	...	...
No. 6........	0.2167	0.00519	0.1803	0.0231	0.2007	0.00881	0.1640	0.0102	0.2380	0.0221	0.1999	0.0304	0.0261	0.0139
No. 9........	0.2037	0.00896	0.2183	0.0118	0.2100	0					0.2107	0.0104	0.00601	0.00692

Specimen No. 9

No. 1........	0.290	...	...	...	...	...	...	...	...	...	0.290	...	...	...
No. 6........	0.355	0	0.355	0	0.385	0.112	0.321	0.0236	0.378	0.0335	0.359	0.00579	0.0226	0.00423
No. 9........	0.325	0	0.300	0	0.280	0					0.302	0.0184	0.0184	0

Specimen No. 10

No. 1........	0.500	...	...	...	...	...	...	...	...	...	0.500	...	...	...
No. 6........	0.674	0.132	0.709	0	0.533	0.0798	0.473	0.0839	0.650	0.0834	0.608	0.125	0.0898	0.00948
No. 9........	0.420	0	0.420	0	0.420	0					0.420	0	0	0

TABLE XX.—SUMMARY OF AVERAGE AND STANDARD DEVIATION VALUES USED IN CONTROL ANALYSIS FOR EACH SPECIMEN BY LABORATORIES.

Average Grain Diameter in Millimeters.

Intercept Method.

Laboratory	Number of Operators	Number of Observations	Average, $\bar{X}$	Standard Deviation Within Individual Operators		Standard Deviation Between Individual Operators		Over-all Standard Deviation	
				Average, $\bar{\sigma}_w$	Corrected, σ'_w	σ_b	Corrected, σ'_b	σ_o	Corrected, σ'_o
SPECIMEN NO. 1									
No. 1	1	1	0.0240	...		...		...	
No. 6	5	15	0.0419	0.00309		0.00683		0.00721	
No. 9	3	9	0.0382	0.00094		0.00113		0.00147	
	9	25	0.0399	0.00228	0.00315	0.00469	0.00484	0.00434	0.00535
SPECIMEN NO. 2									
No. 1	1	1	0.0410	...		...		...	
No. 6	5	15	0.0511	0.00290		0.00628		0.00746	
No. 9	3	9	0.0490	0.00094		0.00082		0.00141	
	9	25	0.0500	0.00217	0.00300	0.00423	0.00430	0.00444	0.00549
SPECIMEN NO. 3									
No. 1	1	1	0.0440	...		...		...	
No. 6	5	15	0.0622	0.00317		0.00657		0.00738	
No. 9	3	9	0.0567	0.00173		0.00196		0.00262	
	9	25	0.0595	0.00263	0.00364	0.00484	0.00526	0.00500	0.00594
SPECIMEN NO. 4									
No. 1	1	1	0.0520	...		...		...	
No. 6	5	15	0.0703	0.00470		0.01150		0.0126	
No. 9	3	9	0.0640	0.00280		0.00330		0.00437	
	9	25	0.0673	0.00399	0.00551	0.00842	0.00912	0.0848	0.0101
SPECIMEN NO. 5									
No. 1	1	1	0.0620	...		...		...	
No. 6	5	15	0.0828	0.00419		0.0156		0.0163	
No. 9	3	9	0.0787	0.00126		0.00288		0.00327	
	9	25	0.0805	0.00309	0.00427	0.0108	0.0113	0.00978	0.0121
SPECIMEN NO. 6									
No. 1	1	1	0.0880	...		...		...	
No. 6	5	15	0.1063	0.00602		0.0230		0.0109	
No. 9	3	9	0.1089	0.00314		0.00314		0.00431	
	9	25	0.1065	0.00494	0.00683	0.0156	0.0158	0.0760	0.00895

TABLE XX.—*Concluded.*

Laboratory	Number of Operators	Number of Observations	Average, $\bar{X}$	Standard Deviation Within Individual Operators		Standard Deviation Between Individual Operators		Over-all Standard Deviation	
				Average, $\bar{\sigma}_w$	Corrected, σ'_w	σ_b	Corrected, σ'_b	σ_o	Corrected, σ'_o
SPECIMEN NO. 7									
No. 1	1	1	0.130	...		...		...	
No. 6	5	15	0.157	0.0128		0.0167		0.0214	
No. 9	3	9	0.164	0		0.0105		0.0105	
	9	25	0.159	0.00800	0.0110	0.0144	0.0172	0.0160	0.0184
SPECIMEN NO. 8									
No. 1	1	1	0.175	...		...		...	
No. 6	5	15	0.200	0.0139		0.0261		0.0304	
No. 9	3	9	0.211	0.00692		0.00601		0.0104	
	9	25	0.203	0.0113	0.0158	0.0186	0.0197	0.0204	0.0243
SPECIMEN NO. 9									
No. 1	1	1	0.290	...		...		...	
No. 6	5	15	0.359	0.0338		0.0226		0.00579	
No. 9	3	9	0.302	0		0.0184		0.0184	
	9	25	0.335	0.00423	0.00584	0.0210	0.0262	0.0121	0.0114
SPECIMEN NO. 10									
No. 1	1	1	0.500	...		...		...	
No. 6	5	15	0.608	0.0758		0.0898		0.125	
No. 9	3	9	0.420	0		0		0	
	9	25	0.536	0.00948	0.0131	0.0561	0.0534	0.0625	0.0823

the nature of the distributions for each laboratory and further substantiate the findings of this study.

The data were also analyzed using the analysis of variances method. For each specimen a test was made to determine whether a significant difference was indicated between the variance between operators and the variance within an operator based on the criteria $P = 0.01$ and $P = 0.05$. A summary of these results is given in Table XVI.

Table XVII presents values of the variance on which the results in Table XVI were based. The standard procedure for analysis of variance was used, where n_1 and n_2 values in terms of number of degrees of freedom were tabulated in each computation; a z value was found and compared with the z values for $P = 0.01$ and $P = 0.05$ read from Table VI of R. A. Fisher's "Statistical Methods for Research Workers."

A study was made of the contribution of the two variations—variation within a single operator and variation between operators—to the total variation for each specimen at each of the two laboratories. Table XVIII gives a summary of these results.

APPENDIX D

STATISTICAL ANALYSIS OF 1940 RESULTS FOR INTERCEPT METHOD

Scope:

This memorandum presents an analysis of the data obtained for the ten series *Y* brass specimens by the intercept method for the determination of grain size by laboratories Nos. 1, 6, and 9. This progress report gives a statistical analysis and summary of these results.

Nature of Data:

Nature of Data in Appendix B describes the procedure, instructions, and forms used in obtaining the test results. Data based on the intercept method were submitted by only three laboratories. Laboratory No. 1 reported only one observation for one operator for each specimen. It used a magnification of 150 × for specimens Nos. 1 to 6, inclusive, and a magnification of 50 × for specimens Nos. 7 to 10, inclusive. Laboratory No. 6 reported three separate observations for five different operators for specimens Nos. 1 to 10, inclusive. It stated that the same equipment used in obtaining the readings by the direct comparison method was used in obtaining readings by the intercept method. Laboratory No. 9 reported three separate observations for three different operators for specimens Nos. 1 to 10, inclusive. The intercept method was applied "using 8 mm, 16 mm, and 32 mm objectives calibrated to a micrometer eyepiece."

Control Analysis of Results:

Following the steps outlined on Form No. 2, "Summary Sheet," average and standard deviation values were computed for the determinations of grain size by each operator, and for all operators combined, for each of the specimens for the data submitted by laboratories Nos. 6 and 9. Using the average value for each operator, the variation between operators at a single laboratory was determined as a standard deviation (σ), the root mean square deviation for averages. Table XIX summarizes these results. The single observation for each specimen obtained by laboratory No. 1 is also included as an average value in the table. No standard deviation values can be given for the results for laboratory No. 1 since only one observation was given for one operator. This table also includes average values of the standard deviation between operators, used to determine control limits. All values outside the 3 σ control limits are designated as a (above) and b (below).

TABLE XXI.—NUMBER AND PERCENTAGE OF AVERAGE VALUES WITHIN CONTROL LIMITS.

Ten Specimens, Three Laboratories.
Average Grain Diameter.
Intercept Method.

Laboratory	Averages for Individual Operators				
	Number of Operators	Above[a]	Below[b]	Within Control Limits	
				No.	Per cent
No. 1.....	1	0	10	0	0
No. 6.....	5	20	9	21	42.0
No. 9.....	3	0	6	24	80.0
	9	20	25	45	50.0

[a] Denotes that average value is greater than upper 3 σ control limits.

[b] Denotes that average value is less than lower 3 σ control limits.

Table XX lists the average value for each specimen determined at each of the three laboratories and the standard deviation values used for control analyses. For each specimen for laboratory No. 1, the average grain size value was below its 3 σ control limits based on the over-all average value for all laboratories combined. No average value for laboratories Nos. 6 and 9 was found to be outside its 3 σ control limits for specimens Nos. 1 to 8, inclusive. All averages for specimens Nos. 9 and 10 were outside their 3

TABLE XXII.—RANKING OF OPERATORS AND LABORATORIES WITH RESPECT TO AVERAGE AND STANDARD DEVIATION VALUES OBTAINED FOR EACH OPERATOR.

Results for Eight Specimens and for all Eight Specimens Combined.

Average Grain Diameter.

Intercept Method.

Operator	Specimen No. 1	Specimen No. 2	Specimen No. 3	Specimen No. 4	Specimen No. 5	Specimen No. 6	Specimen No. 7	Specimen No. 8	Sum of Ranks	Total Rank	Final Ranking		
											Rank	Operator	Laboratory
AVERAGES, $\bar{X}$													
1A	1	1	1	1	1	2	1	2	10	1	1	1A	1
6A	8	8	9	8	8	5	7	7	60	8	2	6B	9
B	2	2	4	4	5	3.5	2	3	25.5	2	3.5	6C	6
C	3.5	5	3	2	2	3.5	5	4	28	3.5	3.5	6D	
D	5	3	6	6	3	1	3	1	28	3.5	5	9A	
E	9	9	8	9	9	9	9	9	71	9	6	9C	
9A	7	6	2	3	6	6.5	4	5	39.5	5	7	9B	
B	6	4	7	5	4	8	8	8	50	7	8	6A	
C	3.5	7	5	7	7	6.5	6	6	48	6	9	6E	
STANDARD DEVIATIONS, σ_w[a]													
6A	8	8	3	4	8	7	8	2	48	7	1	9C	9
B	4	4	8	6	6	1.5	5	8	42.5	5	2	9A	6
C	7	2.5	5	1	4	1.5	6	3	30	4	3	9B	
D	6	7	6	8	7	6	7	5	52	8	4	6C	
E	5	2.5	7	7	5	8	4	7	45.5	6	5	6B	
9A	2	5.5	1	5	2.5	3.5	2	4	25.5	2	6	6E	
B	2	5.5	3	2.5	1	5	2	6	27.0	3	7	6A	
C	2	1	3	2.5	2.5	3.5	2	1	17.5	1	8	6D	

[a] Laboratory No. 1 is omitted from this table. Since only one reading by one operator for each specimen was reported, no standard deviation could be obtained.

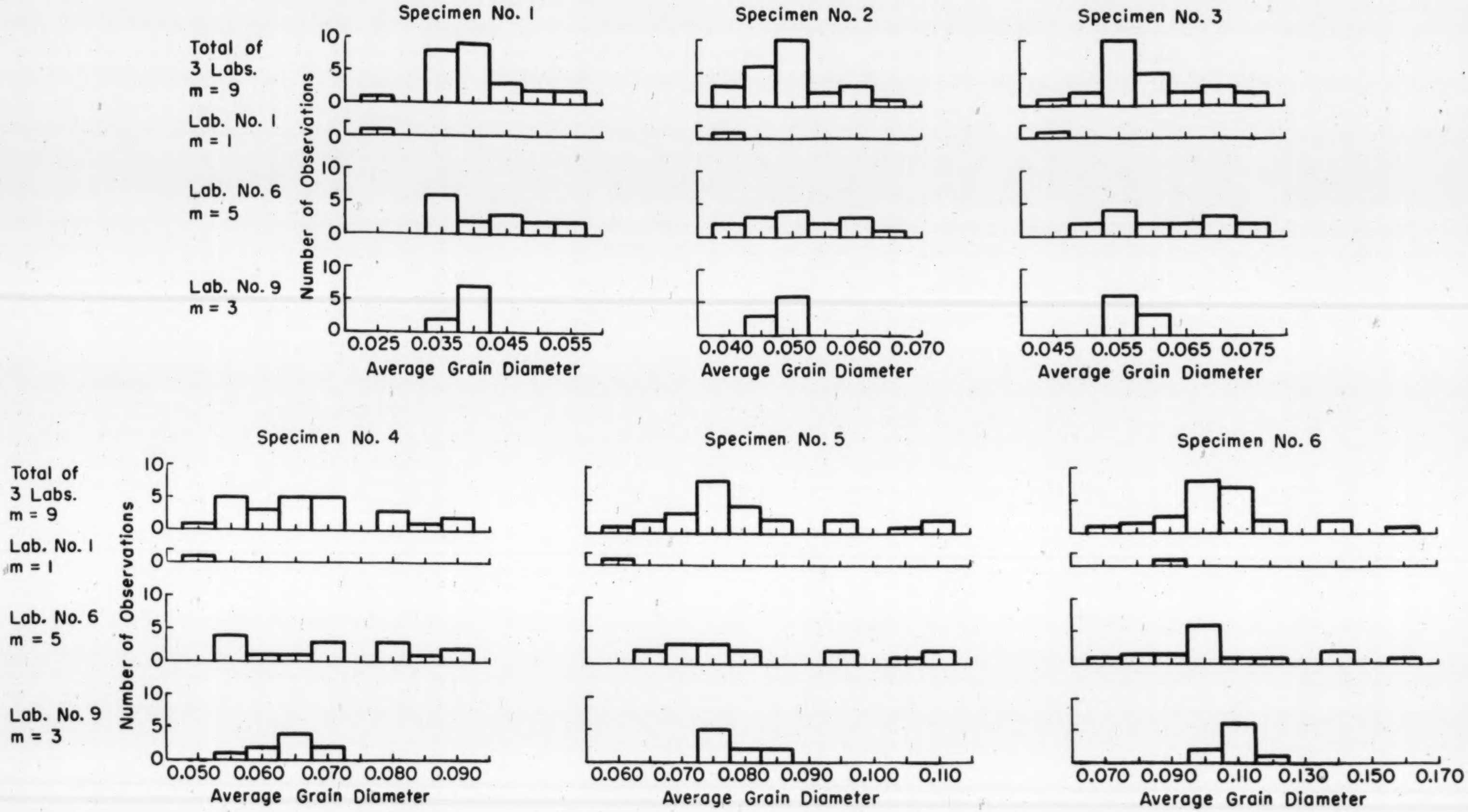
σ control limits. These results, together with those given in Table XIX, indicate in tabular form similar results to those indicated by control charts for average values.

Table XXI presents a summary of the consistency of the results for the three laboratories compared with the over-all results. These findings are presented in terms of the number and percentage of values outside the 3 σ control limits. Since only three laboratories submitted data for the intercept method, these results reflect only the degree of control that was maintained by the nine operators at these laboratories.

Results for specimens Nos. 9 and 10 have been included in the control analysis for information. As in the other progress reports, results for specimens Nos. 9 and 10 are omitted from subsequent analysis results.

Analysis of Results by Ranking:

The average and standard deviation values obtained in this study for each operator may be simplified by means of ordering the operators. This is termed the method of ranking. Since true values are not known for the average grain size of each specimen, rank No. 1 is assigned arbitrarily to the smallest value and rank No. 9 to the largest value determined by the nine operators. Similarly rank No. 1 is assigned to the smallest standard deviation value and rank No. 8 to the largest standard deviation value measuring the variation between repetitive determinations by the same operator (designated herein as the variation within an operator, σ_w). The operator at laboratory No. 1 made only one determination for each specimen and cannot be


Specimen No. 1
Specimen No. 2
Specimen No. 3
Specimen No. 4
Specimen No. 5
Specimen No. 6
Total of 3 Labs. m = 9
Lab. No. 1 m = 1
Lab. No. 6 m = 5
Lab. No. 9 m = 3
Number of Observations
10
5
0
0.025 0.035 0.045 0.055
0.040 0.050 0.060 0.070
0.045 0.055 0.065 0.075
0.050 0.060 0.070 0.080 0.090
0.060 0.070 0.080 0.090 0.100 0.110
0.070 0.090 0.110 0.130 0.150 0.170
Average Grain Diameter

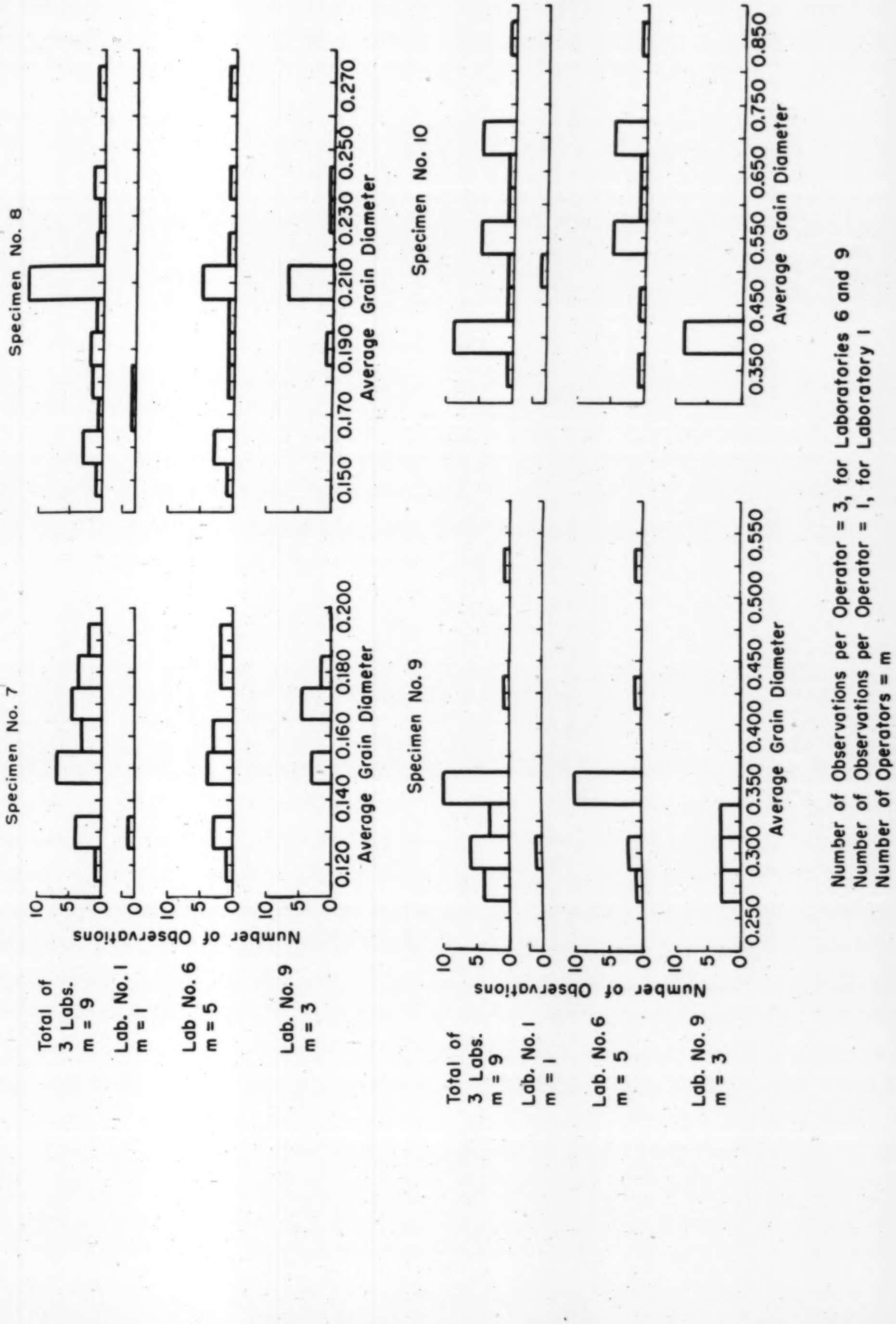


FIG. 6.—Distribution of Average Grain Diameter in Millimeters for Series *Y* Brass in the Intercept Method. Ten specimens, three laboratories.

TABLE XXIII.—SUMMARY OF ANALYSIS OF VARIANCE RESULTS.

Average Grain Diameter.

Intercept Method.

	Variance Between Individual Operators at a Single Laboratory—Significant Difference, $P = 0.01$								Variance Within Individual Operators at a Single Laboratory—Significant Difference, $P = 0.05$							
Specimen..........	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8
Laboratory:																
No. 6........	x	x	x	x	x	x	o	x	x	x	x	x	x	x	x	x
No. 9........	o	o	o	o	x	o	x	o	o	o	o	o	x	o	x	o

NOTE.
x denotes significant difference.
o denotes no significant difference.

TABLE XXIV.—VARIANCE VALUES UPON WHICH RESULTS IN TABLE XXIII ARE BASED.

Average Grain Diameter.

Intercept Method.

Laboratory	Variance	Specimen No. 1	Specimen No. 2	Specimen No. 3	Specimen No. 4	Specimen No. 5	Specimen No. 6	Specimen No. 7	Specimen No. 8
No. 6....	Between operators	0.000175	0.000148	0.000162	0.000494	0.000918	0.001992	0.001048	0.002554
	Within operator	0.000008	0.000024	0.000017	0.000042	0.000032	0.000075	0.000267	0.000369
No. 9....	Between operators	0.000006	0.000003	0.000017	0.000049	0.000046	0.000044	0.000499	0.000162
	Within operator	0.000001	0.000002	0.000005	0.000012	0.000001	0.000017	0	0.000110

included in the ranking for standard deviation values. Table XXII presents a summary of these values and ranks the laboratories with respect to these two statistics. Where average or standard deviation values were the same for several operators, the average of the ranks involved was assigned to each operator.

The results in the table above indicate that operator 1A obtained consistently smaller values for grain size diameter than the other eight operators. The three operators at laboratory No. 9 had smaller variations between repeat measurements for the majority of the specimens than did the other five operators at laboratory No. 6.

Analysis of Distributions and Variations of Results:

Distributions of the actual observations for each of the three laboratories and for the three laboratories combined for each of the ten specimens are presented in Fig. 6. For all specimens the distributions are given using equal cell widths (specimens Nos. 1 to 5: 0.005 mm; specimens Nos. 6 to 8: 0.010 mm; specimen No. 9: 0.025 mm; specimen No. 10: 0.050 mm). These charts indicate the nature of the distribution and the variation in the reported results for each specimen for each laboratory, portray the differences in results for the three laboratories, and further substantiate the findings of this study.

TABLE XXV.—OVER-ALL VARIATION FOR EACH LABORATORY SHOWING CONTRIBUTION OF VARIATION WITHIN AND VARIATION BETWEEN OPERATORS TO OVER-ALL VARIATION.

Average Grain Diameter.
Intercept Method.

Variation	Standard Deviation, σ	Variance, v	Contribution to Total Variation, per cent	Standard Deviation, σ	Variance, v	Contribution to Total Variation, per cent
	SPECIMEN No. 1			**SPECIMEN No. 2**		
	LABORATORY No. 6					
Within single operator	0.00309	0.0000095481	17.0	0.00290	0.0000084100	17.6
Between operators....	0.00683	0.0000466489	83.0	0.00628	0.0000394384	82.4
Total............	0.00750	0.0000561970	100.0	0.00692	0.0000478484	100.0
	LABORATORY No. 9					
Within single operator	0.00094	0.0000008836	40.9	0.00094	0.0000008836	56.8
Between operators....	0.00113	0.0000012769	59.1	0.00082	0.0000006724	43.2
Total............	0.00174	0.0000021605	100.0	0.00125	0.0000015560	100.0
	SPECIMEN No. 3			**SPECIMEN No. 4**		
	LABORATORY No. 6					
Within single operator	0.00317	0.0000100489	18.9	0.00470	0.0000220900	14.3
Between operators....	0.00657	0.0000431649	81.1	0.01150	0.0001322500	85.7
Total............	0.00729	0.0000532138	100.0	0.0124	0.0001543400	100.0
	LABORATORY No. 9					
Within single operator	0.00173	0.0000029929	43.8	0.00280	0.0000078400	41.9
Between operators....	0.00196	0.0000038416	56.2	0.00330	0.0000108900	58.1
Total............	0.00261	0.0000068345	100.0	0.00433	0.0000187300	100.0
	SPECIMEN No. 5			**SPECIMEN No. 6**		
	LABORATORY No. 6					
Within single operator	0.00419	0.0000175561	6.7	0.00602	0.0000362404	6.4
Between operators....	0.01560	0.0002433600	93.3	0.02300	0.0005290000	93.6
Total............	0.01620	0.0002609161	100.0	0.02380	0.0005652404	100.0
	LABORATORY No. 9					
Within single operator	0.00126	0.0000015876	16.1	0.00314	0.0000098596	50.0
Between operators....	0.00288	0.0000082944	83.9	0.00314	0.0000098596	50.0
Total............	0.00314	0.0000098820	100.0	0.00444	0.0000197192	100.0

(Continued on p. 220)

TABLE XXV.—*Concluded.*

Variation	Standard Deviation, σ	Variance, v	Contribution to Total Variation, per cent	Standard Deviation, σ	Variance, v	Contribution to Total Variation, per cent
	SPECIMEN NO. 7			SPECIMEN NO. 8		
	LABORATORY NO. 6					
Within single operator	0.0128	0.0001638400	37.0	0.0139	0.0001932100	22.1
Between operators	0.0167	0.0002788900	63.0	0.0261	0.0006812100	77.9
Total	0.0210	0.0004427300	100.0	0.0296	0.0008744200	100.0
	LABORATORY NO. 9					
Within single operator	0	0	0	0.00692	0.0000478864	57.0
Between operators	0.0105	0.0001102500	100.0	0.00601	0.0000361201	43.0
Total	0.0105	0.0001102500	100.0	0.00917	0.0000840065	100.0

TABLE XXVI.—GRAIN SIZE DETERMINATIONS BY JEFFRIES' METHOD.

Average Grain Diameter in Millimeters Obtained by Three Laboratories for Ten Series *Y* Specimens.

Specimen	Magnification	Laboratory No. 2 Readings	Laboratory No. 5 Reading	Laboratory No. 6 Reading
No. 1	250	0.030 0.025 0.028	0.035	
	150			0.031
No. 2	250	0.040 0.035 0.039	0.055	
	150			0.047
	75	Approx. 0.048		
No. 3	250	0.034 0.041 0.034 0.039 0.041	0.045	
	75	Approx. 0.049		0.052
No. 4	250	0.045 0.050 0.045 0.046	0.050	
	150	0.054 0.052		
	75	0.064	0.060	0.062
No. 5	250	0.060	0.075	
	150	0.057 0.055 0.068		
	75	0.073	0.080	0.071
No. 6	75	0.109 0.108	0.120	0.106
No. 7	75	0.146 0.144	0.165	0.164
No. 8	75	0.216 0.199	0.225	0.200
No. 9	75	0.356 0.370	0.450	
	25	0.417 0.439	0.520	0.415
No. 10	75	0.422 0.445	0.470	
	25	0.525 0.535	0.640	0.666

TABLE XXVII.—AVERAGE AND STANDARD DEVIATION VALUES FOR GRAIN SIZE DETERMINATIONS BY JEFFRIES' METHOD.

Based on Data of Table XXVI.

Specimen	Magnification	Laboratory No. 2			Laboratory No. 5			Laboratory No. 6			Over-all Average for Each Magnification, $\overline{X}$	Over-all Average, $\overline{X}$	Over-all Standard Deviation, σ_0
		n	$\overline{X}$	σ	n	$\overline{X}$	σ	n	$\overline{X}$	σ			
No. 1....	250	3	0.028	0.0021	1	0.035	...				0.030		
	150							1	0.031	...	0.031		
	All	3	0.028	0.0021	1	0.035	...	1	0.031	...		0.0300	0.00332
No. 2....	250	3	0.038	0.0022	1	0.055	...				0.042		
	150							1	0.047	...	0.047		
	75	1	0.048	...							0.048		
	All	4	0.0405	0.0046	1	0.055	...	1	0.047	...		0.0440	0.00668
No. 3....	250	5	0.038	0.0032	1	0.045	...				0.039		
	75	1	0.049	...				1	0.052	...	0.0505		
	All	6	0.0397	0.0051	1	0.045	...	1	0.052	...		0.0419	0.00609
No. 4....	250	4	0.0465	0.0021	1	0.050	...				0.047		
	150	2	0.053	0.001							0.053		
	75	1	0.064	...	1	0.060	...	1	0.062	...	0.062		
	All	7	0.0509	0.0063	2	0.055	0.0050	1	0.062	...		0.0528	0.00669
No. 5....	250	1	0.060	...	1	0.075	...				0.0725		
	150	3	0.060	0.0057							0.060		
	75	1	0.073	...	1	0.080	...	1	0.071	...	0.075		
	All	5	0.0626	0.0063	2	0.0775	0.0025	1	0.071	...		0.0674	0.00851
No. 6....	75	2	0.1085	0.0005	1	0.120	...	1	0.106	...	0.111		
	All	2	0.1085	0.0005	1	0.120	...	1	0.106	...		0.111	0.00545
No. 7....	75	2	0.145	0.0010	1	0.165	...	1	0.164	...	0.155		
	All	2	0.145	0.0010	1	0.165	...	1	0.164	...		0.155	0.00978
No. 8....	75	2	0.2075	0.0085	1	0.225	...	1	0.200	...	0.210		
	All	2	0.2075	0.0085	1	0.225	...	1	0.200	...		0.210	0.01098
No. 9....	75	2	0.363	0.007	1	0.450	...				0.392		
	25	2	0.428	0.011	1	0.520	...	1	0.415	...	0.448		
	All	4	0.3955	0.0338	2	0.485	0.035	1	0.415	...		0.424	0.05041
No. 10....	75	2	0.4335	0.0115	1	0.470	...				0.446		
	25	2	0.530	0.005	1	0.640	...	1	0.666	...	0.5915		
	All	4	0.4818	0.0491	2	0.555	0.085	1	0.666	...		0.529	0.08712

The data were also analyzed using the analysis of variances method. For each specimen a test was made to determine whether a significant difference was indicated between the variance between operators and the variance within an operator based on the criteria $P = 0.01$ and $P = 0.05$. A summary of these results is given in Table XXIII.

Table XXIV presents values of the variance on which the results in Table XXIII were based. The standard procedure for analysis of variance was used, where n_1 and n_2 values in terms of number of degrees of freedom were tabulated in each computation; a z value was found and compared with the z values for $P = 0.01$ and $P = 0.05$ read from Table VI of R. A. Fisher's "Statistical Methods for Research Workers."

A study was made of the contribution of the two variations—variation within a single operator and variation between operators—to the total variation for each specimen at laboratory Nos. 6 and 9.

Laboratory No. 1 could not be included in this study inasmuch as no standard deviation value could be computed from a single observation. Table XXV gives a summary of these results. For laboratory No. 6 the per cent contribution of the variation between operators to the over-all variation is 63.0 per cent or more for specimens Nos. 1 to 8, inclusive, with an average value of 82.5 per cent. For laboratory No. 9 the per cent contribution of the variation between operators to the over-all variation is 43.0 per cent or more for specimens Nos. 1 to 8, inclusive, with an average value of 61.7 per cent.

APPENDIX E

STATISTICAL ANALYSIS OF 1940 RESULTS FOR JEFFRIES' METHOD

Scope:

This memorandum presents an analysis of the data obtained for the ten series *Y* brass specimens by the Jeffries' method for the determination of grain size by laboratories Nos. 2, 5, and 6. This progress report gives a statistical analysis and summary of these results and also a brief comparison between the average of these values and similar averages obtained by the three other methods described in the preceding three appendices.

Nature of Data:

The data for laboratory No. 2 consists of several readings per specimen, in many instances at different magnifications. For laboratories Nos. 5 and 6 single readings are given for each specimen. Laboratory No. 5 gives values for two different magnifications for seven specimens. These data, being few in number, are listed in Table XXVI.

Analysis of Results:

Average and standard deviation values were determined, where possible. When only one observation is given, no standard deviation can be obtained. Table XXVII gives n, $\overline{X}$, and σ values for each laboratory for each specimen and for each magnification. Two sets of over-all average values are listed for each specimen, a set of average values for each magnification, and a single over-all value based on all the determinations regardless of magnification. Each determination is given equal weight so that

TABLE XXVIII.—TEST FOR SIGNIFICANT DIFFERENCE BETWEEN AVERAGES FOR THREE LABORATORIES TAKEN TWO AT A TIME USING THE JEFFRIES' METHOD.

Based on Standard Deviation Values for Laboratory No. 2.

Specimen	Magnification	Laboratories			Standard Deviation, σ
		No. 2 *versus* No. 5	No. 2 *versus* No. 6	No. 5 *versus* No. 6	
No. 1.......	250	2.89	[a]	[a]	0.0021
No. 2.......	250	6.69	[a]	[a]	0.0022
No. 3.......	250	2.00	[a]	[a]	0.0032
	75	[a]	3.00	[a]	0.001[b]
No. 4.......	250	1.49	[a]	[a]	0.0021
	75	4.00	2.00	2.00	0.001[b]
No. 5.......	250	7.50	[a]	[a]	0.002[b]
	75	7.00	2.00	9.00	0.001[b]
No. 6.......	75	18.78	4.08	28.00	0.0005
No. 7.......	75	16.32	15.51	1.00	0.001
No. 8.......	75	1.68	0.72	0.29	0.0085
No. 9.......	75	10.15	[a]	[a]	0.007
	25	6.83	0.96	9.55	0.011
No. 10.......	75	2.59	[a]	[a]	0.0115
	25	17.96	22.21	5.20	0.005

[a] Results obtained at different magnification; see Table XXVI.

[b] Assumed value estimated from results for other specimens.

NOTE.—Average values were considered significantly different if $t > 3$ where t is obtained from the relation:

$$t = \frac{\overline{X}_1 - \overline{X}_2}{\sigma\sqrt{\frac{1}{n_1} + \frac{1}{n_2}}}$$

the results from laboratory No. 2 have more weight since more readings were obtained there. An over-all standard deviation value, σ_o, is given based on all observations from the three laboratories combined.

No tests for control are possible with such meager data. Using the standard deviation values obtained for laboratory No. 2, a test for significant difference between laboratories Nos. 2 *versus* 5, 2 *versus* 6, and 5 *versus* 6 give the results shown in Table XXVIII.

TABLE XXIX.—RANKING OF LABORATORIES WITH RESPECT TO AVERAGE VALUES.

Jeffries' Method.

FOR EACH MAGNIFICATION

Laboratory	Specimen and Magnification														
	No. 1	No. 2	No. 3		No. 4		No. 5		No. 6	No. 7	No. 8	No. 9		No. 10	
	250	250	250	75	250	75	250	75	75	75	75	75	25	75	25
No. 2.....	1	1	1	1	1	3	1	2	2	1	2	1	2	1	1
No. 5.....	2	2	2	...	2	1	2	3	3	3	3	2	3	2	2
No. 6.....	...	...	...	2	...	2	...	1	1	2	1	...	1	...	...

FOR OVER-ALL AVERAGES

	Specimen									
	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8	No. 9	No. 10
No. 2....	1	1	1	1	1	2	1	2	2	1
No. 5....	3	3	2	2	3	3	3	3	3	2
No. 6....	2	2	3	3	2	1	2	1	1	3

NOTE.—Rank No. 1 = smallest value; rank No. 2 = intermediate value; rank No. 3 = largest value.

Taking account of the magnifications used and also using over-all average values, the results for the three laboratories may be ranked, giving the smallest average value rank No. 1, etc. Table XXIX lists these results.

COMPARISON OF RESULTS OBTAINED BY FOUR DIFFERENT METHODS

In order to evaluate the different methods, a study was made of the differences between the over-all results obtained by each laboratory by the four methods. If no results were obtained for one or more of the methods, a note is made to that effect in the attached tables. A table composed of three parts is given for each laboratory and also for all laboratories combined. The first part of each table gives the n, $\bar{X}$, and σ values for each method for each specimen. The second part gives t values obtained by a test for significant difference between the averages for the various methods where:

$$t_{\bar{X}} = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\frac{\sigma_1^2}{n_1} + \frac{\sigma_2^2}{n_2}}}$$

The third part of each table gives t values obtained by a test for significant difference between over-all σ values where:

$$t_\sigma = \frac{\sigma_1 - \sigma_2}{\sqrt{\frac{\sigma_1^2}{2n_1} + \frac{\sigma_2^2}{2n_2}}}$$

Table XXX covers laboratory No. 2 alone; Table XXXI covers laboratory No. 5 alone; Table XXXII covers laboratory No. 6 alone; and Table XXXIII covers the results for all laboratories combined, including, where possible, results for each laboratory that gave results for any of the methods.

TABLE XXX.—COMPARISON BETWEEN AVERAGE AND STANDARD DEVIATION VALUES FOR AVERAGE GRAIN DIAMETER OBTAINED BY FOUR DIFFERENT METHODS.

Results for Laboratory No. 2.

n, $\overline{X}$, AND σ VALUES

Specimen	Method A			Method B			Method C			Method D		
	Comparison Method			Transparency Method			Intercept Method			Jeffries' Method		
	n	$\overline{X}$	σ	n	$\overline{X}$	σ	n	$\overline{X}$	σ	n	$\overline{X}$	σ
No. 1	9	0.0326	0.00224	9	0.0306	0.00195	[a]	[a]	[a]	3	0.028	0.0021
No. 2	9	0.0422	0.00249	9	0.0394	0.00284	[a]	[a]	[a]	4	0.0405	0.0046
No. 3	9	0.0517	0.00577	9	0.0460	0.00537	[a]	[a]	[a]	6	0.0397	0.0051
No. 4	9	0.0600	0.00499	9	0.0522	0.00485	[a]	[a]	[a]	7	0.0509	0.0063
No. 5	9	0.0733	0.00745	9	0.0722	0.00749	[a]	[a]	[a]	5	0.0626	0.0063
No. 6	9	0.0983	0.00972	9	0.093	0.00568	[a]	[a]	[a]	2	0.1085	0.0005
No. 7	9	0.154	0.0120	9	0.153	0.00667	[a]	[a]	[a]	2	0.145	0.001
No. 8	9	0.184	0.0142	9	0.174	0.00831	[a]	[a]	[a]	2	0.2075	0.0085
No. 9	[b]	[b]	[b]	[b]	[b]	[b]	[a]	[a]	[a]	4	0.2955	0.0338
No. 10	[b]	[b]	[b]	[b]	[b]	[b]	[a]	[a]	[a]	4	0.4818	0.0491

TEST FOR SIGNIFICANT DIFFERENCE BETWEEN AVERAGES

Specimen	*D versus A*	*D versus B*	*D versus C*	*C versus A*	*C versus B*	*B versus A*
No. 1	1.08	1.89				2.02
No. 2	0.70	0.44				2.22
No. 3	4.23	2.29				2.17
No. 4	3.13	0.45				3.36
No. 5	2.91	2.61				0.31
No. 6	3.13	8.05				1.41
No. 7	2.22	3.43				0.22
No. 8	3.07	5.06				1.82
No. 9	[b]	[b]				[b]
No. 10	[b]	[b]				[b]

TEST FOR SIGNIFICANT DIFFERENCE BETWEEN STANDARD DEVIATIONS

Specimen	*D versus A*	*D versus B*	*D versus C*	*C versus A*	*C versus B*	*B versus A*
No. 1	0.14	0.15				0.41
No. 2	1.22	1.00				0.39
No. 3	0.33	0.14				0.22
No. 4	0.64	0.71				0.09
No. 5	0.44	0.46				0.02
No. 6	4.00	3.80				1.52
No. 7	3.83	3.44				1.65
No. 8	1.05	0.04				1.52
No. 9	[b]	[b]				[b]
No. 10	[b]	[b]				[b]

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[a] No results for intercept method.

[b] Results for specimens Nos. 9 and 10 are only approximations and hence have been omitted.

TABLE XXXI.—COMPARISON BETWEEN AVERAGE AND STANDARD DEVIATION VALUES FOR AVERAGE GRAIN DIAMETER OBTAINED BY FOUR DIFFERENT METHODS.

Results for Laboratory No. 5.

n, $\overline{X}$, AND σ VALUES

Specimen	Method A			Method B			Method C			Method D		
	Comparison Method			Transparency Method			Intercept Method			Jeffries' Method		
	n	$\overline{X}$	σ	n	$\overline{X}$	σ	n	$\overline{X}$	σ	n	$\overline{X}$	σ
No. 1..........	9	0.0370	0.00343	[a]	[a]	[a]	[a]	[a]	[a]	1	0.035	0.0021 [b]
No. 2..........	9	0.0461	0.00314	[a]	[a]	[a]	[a]	[a]	[a]	1	0.055	0.0022 [b]
No. 3..........	9	0.0606	0.00761	[a]	[a]	[a]	[a]	[a]	[a]	1	0.045	0.0032 [b]
No. 4..........	9	0.0722	0.00629	[a]	[a]	[a]	[a]	[a]	[a]	2	0.055	0.0050
No. 5..........	9	0.0894	0.00497	[a]	[a]	[a]	[a]	[a]	[a]	2	0.0775	0.0025
No. 6..........	9	0.1122	0.00916	[a]	[a]	[a]	[a]	[a]	[a]	1	0.120	0.0005 [b]
No. 7..........	9	0.157	0.0115	[a]	[a]	[a]	[a]	[a]	[a]	1	0.165	0.0010 [b]
No. 8..........	9	0.202	0.0187	[a]	[a]	[a]	[a]	[a]	[a]	1	0.225	0.0085 [b]
No. 9..........	[c]	[c]	[c]	[a]	[a]	[a]	[a]	[a]	[a]	2	0.485	0.035
No. 10..........	[c]	[c]	[c]	[a]	[a]	[a]	[a]	[a]	[a]	2	0.555	0.085

TEST FOR SIGNIFICANT DIFFERENCE BETWEEN AVERAGES

Specimen	*D versus A*	*D versus B*	*D versus C*	*C versus A*	*C versus B*	*B versus A*
No. 1..........	0.87	[a]	[a]	[a]	[a]	[a]
No. 2..........	3.65	[a]	[a]	[a]	[a]	[a]
No. 3..........	3.82	[a]	[a]	[a]	[a]	[a]
No. 4..........	4.18	[a]	[a]	[a]	[a]	[a]
No. 5..........	4.91	[a]	[a]	[a]	[a]	[a]
No. 6..........	2.52	[a]	[a]	[a]	[a]	[a]
No. 7..........	2.02	[a]	[a]	[a]	[a]	[a]
No. 8..........	2.18	[a]	[a]	[a]	[a]	[a]
No. 9..........	[c]	[a]	[a]	[a]	[a]	[a]
No. 10..........	[c]	[a]	[a]	[a]	[a]	[a]

TEST FOR SIGNIFICANT DIFFERENCE BETWEEN STANDARD DEVIATIONS

Spceimen	*D versus A*	*D versus B*	*D versus C*	*C versus A*	*C versus B*	*B versus A*
No. 1..........	0.79	[a]	[a]	[a]	[a]	[a]
No. 2..........	0.55	[a]	[a]	[a]	[a]	[a]
No. 3..........	1.53	[a]	[a]	[a]	[a]	[a]
No. 4..........	0.44	[a]	[a]	[a]	[a]	[a]
No. 5..........	1.44	[a]	[a]	[a]	[a]	[a]
No. 6..........	3.96	[a]	[a]	[a]	[a]	[a]
No. 7..........	3.75	[a]	[a]	[a]	[a]	[a]
No. 8..........	1.37	[a]	[a]	[a]	[a]	[a]
No. 9..........	[c]	[a]	[a]	[a]	[a]	[a]
No. 10..........	[c]	[a]	[a]	[a]	[a]	[a]

[a] No results for transparency and intercept methods.

[b] Based on σ values for laboratory No. 2.

[c] Results for specimens Nos. 9 and 10 are only approximations and hence have been omitted.

TABLE XXXII.—COMPARISON BETWEEN AVERAGE AND STANDARD DEVIATION VALUES FOR AVERAGE GRAIN DIAMETER OBTAINED BY FOUR DIFFERENT METHODS.

Results for Laboratory No. 6.

n, $\overline{X}$, AND σ VALUES

Specimen	Method A			Method B			Method C			Method D		
	Comparison Method			Transparency Method			Intercept Method[d]			Jeffries' Method		
	n	$\overline{X}$	σ	n	$\overline{X}$	σ	n	$\overline{X}$	σ	n	$\overline{X}$	σ
No. 1	15	0.0303	0.00125	[a]	[a]	[a]	15	0.0419	0.00721	1	0.031	0.0021[b]
No. 2	15	0.0410	0.00200	[a]	[a]	[a]	15	0.0511	0.00746	1	0.047	0.0022[b]
No. 3	15	0.0587	0.00694	[a]	[a]	[a]	15	0.0622	0.00738	1	0.052	0.0032[b]
No. 4	15	0.0670	0.00969	[a]	[a]	[a]	15	0.0703	0.0126	1	0.062	0.0063[b]
No. 5	15	0.0860	0.00688	[a]	[a]	[a]	15	0.0828	0.0163	1	0.071	0.0063[b]
No. 6	15	0.1033	0.00675	[a]	[a]	[a]	15	0.1063	0.0109	1	0.106	0.0005[b]
No. 7	15	0.160	0.0200	[a]	[a]	[a]	15	0.1570	0.0214	1	0.164	0.0010[b]
No. 8	15	0.193	0.0289	[a]	[a]	[a]	15	0.200	0.0304	1	0.200	0.0085[b]
No. 9	[c]	[c]	[c]	[a]	[a]	[a]	15	0.359	0.00579	1	0.415	0.034[b]
No. 10	[c]	[c]	[c]	[a]	[a]	[a]	15	0.608	0.125	1	0.666	0.049[b]

TEST FOR SIGNIFICANT DIFFERENCE BETWEEN AVERAGES

Specimen	*D versus A*	*D versus B*	*D versus C*	*C versus A*	*C versus B*	*B versus A*
No. 1	0.33	[a]	3.88	5.61	[a]	[a]
No. 2	2.65	[a]	1.40	5.07	[a]	[a]
No. 3	1.83	[a]	2.74	1.34	[a]	[a]
No. 4	0.74	[a]	1.17	0.80	[a]	[a]
No. 5	2.29	[a]	1.56	0.70	[a]	[a]
No. 6	1.49	[a]	0.10	0.91	[a]	[a]
No. 7	0.76	[a]	1.25	0.40	[a]	[a]
No. 8	0.62	[a]	0	0.65	[a]	[a]
No. 9	[c]	[a]	1.65	[c]	[a]	[a]
No. 10	[c]	[a]	0.99	[c]	[a]	[a]

TEST FOR SIGNIFICANT DIFFERENCE BETWEEN STANDARD DEVIATIONS

Specimen	*D versus A*	*D versus B*	*D versus C*	*C versus A*	*C versus B*	*B versus A*
No. 1	0.57	[a]	2.58	4.46	[a]	[a]
No. 2	0.13	[a]	2.54	3.87	[a]	[a]
No. 3	1.44	[a]	1.59	2.26	[a]	[a]
No. 4	0.71	[a]	1.26	1.00	[a]	[a]
No. 5	0.13	[a]	1.87	2.92	[a]	[a]
No. 6	4.88	[a]	5.15	1.77	[a]	[a]
No. 7	5.11	[a]	5.14	0.26	[a]	[a]
No. 8	2.55	[a]	1.89	0.20	[a]	[a]
No. 9	[c]	[a]	1.17	[c]	[a]	[a]
No. 10	[c]	[a]	1.83	[c]	[a]	[a]

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[a] No results for transparency method.

[b] Based on σ values for laboratory No. 2.

[c] Results for specimens Nos. 9 and 10 are only approximations and hence have been omitted.

[d] Based on data submitted May 8, 1942. Dec. 22, 1941, data gives: 0.31, 0.041, 0.054, 0.062, 0.073, 0.103, 0.163, 0.204, 0.480, and 0.700 as single readings obtained for specimens Nos. 1 to 10, respectively.

TABLE XXXIII.—COMPARISON BETWEEN AVERAGE AND STANDARD DEVIATION VALUES FOR AVERAGE GRAIN DIAMETER OBTAINED BY FOUR DIFFERENT METHODS.

Over-All Results for All Laboratories Obtaining Results by Any Method.

n, $\overline{X}$, AND σ VALUES

Specimen	Method A			Method B			Method C			Method D		
	Comparison Method			Transparency Method			Intercept Method			Jeffries' Method		
	n	$\overline{X}$	σ	n	$\overline{X}$	σ	n	$\overline{X}$	σ	n	$\overline{X}$	σ
No. 1	96	0.0332	0.00271	24	0.0305	0.00201	25	0.0399	0.00434	5	0.0300	0.00332
No. 2	96	0.0422	0.00225	24	0.0404	0.00278	25	0.0500	0.00444	6	0.0440	0.00668
No. 3	96	0.0525	0.00497	24	0.0485	0.00622	25	0.0595	0.00500	8	0.0419	0.00609
No. 4	96	0.0629	0.00547	24	0.0550	0.00677	25	0.0675	0.00848	10	0.0528	0.00669
No. 5	96	0.0790	0.00544	24	0.0729	0.00758	25	0.0805	0.00978	8	0.0674	0.00851
No. 6	96	0.1015	0.00715	24	0.101	0.00767	25	0.1065	0.00760	4	0.111	0.00545
No. 7	96	0.153	0.0121	24	0.165	0.0141	25	0.159	0.0160	4	0.155	0.00978
No. 8	96	0.188	0.122	24	0.191	0.0146	25	0.203	0.0204	4	0.210	0.0110
No. 9	[a]	[a]	[a]	[a]	[a]	[a]	25	0.335	0.0121	7	0.424	0.0504
No. 10	[a]	[a]	[a]	[a]	[a]	[a]	25	0.536	0.0625	7	0.529	0.0871

TEST FOR SIGNIFICANT DIFFERENCE BETWEEN AVERAGES

Specimen	*D versus A*	*D versus B*	*D versus C*	*C versus A*	*C versus B*	*B versus A*
No. 1	2.12	0.32	5.76	7.35	9.79	5.46
No. 2	0.66	1.29	2.09	8.51	9.11	2.94
No. 3	4.79	2.64	7.41	6.24	6.81	2.93
No. 4	4.62	0.87	5.42	2.58	5.71	5.30
No. 5	3.78	1.63	3.65	0.73	3.05	3.71
No. 6	0.61	3.10	1.36	2.52	2.52	0.29
No. 7	0.40	1.76	0.68	1.75	1.39	3.83
No. 8	3.58	3.04	1.02	3.05	2.38	0.74
No. 9	[a]	[a]	4.63	[a]	[a]	[a]
No. 10	[a]	[a]	0.20	[a]	[a]	[a]

TEST FOR SIGNIFICANT DIFFERENCE BETWEEN STANDARD DEVIATIONS

Specimen	*D versus A*	*D versus B*	*D versus C*	*C versus A*	*C versus B*	*B versus A*
No. 1	0.57	1.20	0.84	2.53	3.43	2.05
No. 2	2.29	1.98	1.10	3.38	2.23	1.22
No. 3	0.72	0.07	0.65	0.04	1.07	1.29
No. 4	0.79	0.04	0.93	2.38	0.46	1.23
No. 5	1.42	0.38	0.50	3.02	1.25	1.84
No. 6	0.85	1.00	0.95	0.38	0.05	0.43
No. 7	0.65	1.67	1.51	2.47	6.24	0.90
No. 8	0.30	0.81	1.94	2.72	1.62	1.05
No. 9	[a]	[a]	2.82	[a]	[a]	[a]
No. 10	[a]	[a]	0.99	[a]	[a]	[a]

[a] Results for specimens Nos. 9 and 10 are only approximations and hence have been omitted.

APPENDIX F

COMPOSITE TABLE CONTRASTING THE OVER-ALL RESULTS OBTAINED FROM THE DIRECT COMPARISON METHOD AND THE TRANSPARENCY METHOD

(Composite Table based on Table IV, Appendix B, and on Table XIV, Appendix C)

NUMBER AND PERCENTAGE OF AVERAGE VALUES WITHIN CONTROL LIMITS.
Average Grain Diameter.
Eight Specimens.

Laboratory	Over-all Average				Averages for Individual Operators				
	Above[a]	Below[b]	Within Control Limits		No. of Operators	Above[a]	Below[b]	Within Control Limits	
			No.	Per Cent				No.	Per Cent
DIRECT COMPARISON METHOD—NINE LABORATORIES									
No. 1	0	6	2	25.0	5	0	23	17	42.5
No. 2	0	0	8	100.0	3	2	5	17	70.8
No. 3	2	0	6	75.0	3	8	0	16	66.7
No. 4	0	6	2	25.0	4	0	11	21	65.6
No. 5	7	0	1	12.5	3	13	0	11	45.8
No. 6	2	1	5	62.5	5	14	5	21	52.5
No. 7	1	0	7	87.5	3	1	2	21	87.5
No. 8	1	1	6	75.0	3	5	1	18	75.0
No. 9	3	0	5	62.5	3	8	1	15	62.5
	16	14	42	58.3	32	51	48	157	61.3
TRANSPARENCY METHOD—TWO LABORATORIES									
No. 1	0	0	8	100.0	5	2	1	37	92.5
No. 2	0	0	8	100.0	3	0	2	22	91.7
	0	0	16	100.0	8	2	3	59	92.1

[a] Denotes that average value is greater than upper 3 σ control limits.
[b] Denotes that average value is greater than lower 3 σ control limits.

APPENDIX III

THE MECHANICAL PROPERTIES OF SOME NICKEL SILVER ALLOY STRIPS*

By G. R. Gohn,[1] J. P. Guerard,[1] and G. J. Herbert[1]

Synopsis

This paper presents data on the mechanical properties—including tensile strength, proportional limit, yield strength, modulus of elasticity, elongation, Rockwell hardness and fatigue characteristics—of four nickel silver alloys in the form of strip. The alloys include the standard 18 and 12 per cent nickel alloys (alloys Nos. 4 and 8 of ASTM Specification B 122 - 52 T), a high-copper 12 per cent nickel silver alloy, and a 10 per cent nickel silver alloy. The data indicate that either of the two 12 per cent nickel alloys have mechanical properties that make them suitable as engineering substitutes for the 18 per cent nickel alloy in spring applications. On the other hand, the properties of the 10 per cent alloys are such that it is not a satisfactory substitute for springs.

Nickel silver strip has long been used as an engineering material in the manufacture of small, flat, or formed, punched springs. Generally, the 18 per cent nickel alloy has been specified because of its good mechanical properties. Its high elastic strength, good fatigue characteristics and satisfactory electrical conductivity, the ease with which it can be welded, its good resistance to corrosion, and pleasing appearance all have been factors in the selection of the 18 per cent nickel silver alloy for these applications and for its general use as the base for silver-plated ware.

During World War II, the shortage of nickel made it necessary to restrict markedly the use of nickel silver strip. Various alloys were investigated as possible substitutes. Among the most promising, were the 12 per cent nickel alloys. Preliminary studies showed that the mechanical properties of these 12 per cent nickel alloys and the standard 18 per cent nickel alloys were similar. Accordingly as an alternative, G. R. Gohn, and J. P. Guerard proposed that the amount of nickel silver available for spring applications could be increased by at least 50 per cent if an alloy of 12 per cent nickel, 56.5 per cent copper, balance zinc were used in lieu of the standard 18 per cent alloy. After study by a task group, such an alloy was accepted by ASTM Committee B-5 on Copper and Copper Alloys, and specification requirements for the 12 per cent nickel alloy (designated No. 8) were incorporated in ASTM Specifications B-122 in 1946.[2]

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* Presented during the meetings of Committe B-5 on Copper and Copper Alloys, Cast and Wrought, in conjunction with Committee Week of the Society, February 1-5, 1954.

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[2] Tentative Specifications for Copper-Nickel-Zinc and Copper-Nickel Alloy Sheet and Strip (B 122 - 46a T), 1946 Book of ASTM Standards, Part 1-B, p. 402.

The end of the war temporarily relieved the nickel shortage but, with the outbreak of the Korean conflict, restrictions were again imposed on the use of nickel. This time specific limitations on the use of nickel prevented general usage of the 18 per cent alloy. This restriction resulted in a greater use of the 12 per cent alloy and encouraged further studies of the mechanical properties of the low-nickel material. Recently, restrictions on the use of nickel have been lifted. However, the need for nickel in critical applications such as jet engines, gas turbines, rockets, guided missiles, and similar devices demands that no more nickel than is necessary be used on any application. The data in this paper are presented to show one area in which critical nickel can be conserved without any significant engineering sacrifice.

Four nickel silver alloys are included in these studies. The first is the standard 18 per cent nickel, 55 per cent copper, 27 per cent zinc alloy designated as No. 4 in ASTM Specification B 122 - 52 T.[3] The second alloy is known as No. 8 in Specification B 122 and has a nominal composition of 12 per cent nickel, 56.5 per cent copper, and 31.5 per cent zinc. The third alloy is a modification of alloy No. 8 in which the nominal copper content in the material tested has been increased to 60 per cent with a corresponding reduction in the zinc content. The fourth alloy contains 10 per cent nickel, 60 per cent copper, and 30 per cent zinc. The allowable ranges in composition for these four alloys are given in Table I.

TABLE I.—CHEMICAL REQUIREMENTS FOR NICKEL SILVER ALLOYS.

Alloy	Copper, per cent	Nickel,[a] per cent	Lead, max per cent	Iron, max per cent	Manganese, max per cent	Zinc, per cent
No. 4 (ASTM B 122 - 52 T) (55 Cu, 18 Ni, 27 Zn)	53.5 to 56.5	16.5 to 19.5	0.10	0.25	0.50	remainder
No. 8 (ASTM B 122 - 52 T) (56.5 Cu, 12 Ni, 31.5 Zn)	55.0 to 58.0	11.0 to 13.5	0.10	0.25	0.50	remainder
60 per cent Copper, 12 per cent Nickel	55.0 to 61.0	11.0 to 13.5	0.10	0.35	0.50	remainder
60 per cent Copper, 10 per cent Nickel	59.0 to 63.0	9.0 to 11.0	0.10	0.35	0.50	remainder

[a] Cobalt counting as nickel.

Since the data on the 18 per cent nickel silver alloy include not only some previously published information (**1, 2, 3, 4**)[4] but some additional new data obtained by the authors, the various analyses are not readily available but all alloys tested conformed to specification limits, as did all of the standard 12 per cent nickel silver alloys. A representative analysis for the standard 12 per cent nickel alloys studied is as follows:

Copper, per cent	57.73
Nickel, per cent	11.52
Zinc, per cent	30.33
Manganese, per cent	0.15
Iron, per cent	0.17
Phosphorus, per cent	0.002
Lead, per cent	0.03

The only difference in composition between this series of alloys and the high-copper 12 per cent nickel silver alloys is the increase in copper content to a nominal value of 60 per cent for the alloys tested.

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[3] Tentative Specification for Copper-Nickel Zinc Alloy (Nickel Silver) and Copper-Nickel Alloy Plate, Sheet, Strip, and Rolled Bar (B 122 - 52 T), 1952 Book of ASTM Standards, Part 2, p. 331.

[4] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 256.

In the case of the 10 per cent nickel silver alloys, the material studied had the following composition:

Copper, per cent	60.7
Nickel, per cent	9.5
Manganese, per cent	0.07
Iron, per cent, less than	0.10
Lead, per cent	0.02
Phosphorus, per cent	0.01
Tin, per cent	trace
Bismuth, per cent	trace
Zinc, per cent	remainder

The tensile properties of the various alloys were determined in accordance with ASTM Method E 8[5] using specimens conforming to Fig. 6 of those methods for all tests made since 1945. Prior to that time an 8-in. gage length test specimen was used for all tests where data are reported for the proportional limit and yield strength values. The fatigue data were obtained from reversed bending fatigue tests as described by Greenall and Gohn (2).

The mechanical test data are summarized in Table II for the 18 per cent nickel alloys, in Table III for the standard 12 per cent nickel alloys, in Table IV for the high-copper 12 per cent nickel alloys, and in Table V for the high-copper 10 per cent nickel alloys.

The relation between per cent reduction by cold rolling and tensile strength for the four compositions is given in Fig. 1. Figure 2 shows the relationship between per cent reduction by cold rolling and Rockwell hardness for the same materials. The effect of cold rolling on the average mechanical properties of the various alloys studied is shown in Fig. 3. A study of these data shows that cold rolling causes the expected increase in tensile strength and Rockwell hardness in all four alloys. The increase in Rockwell hardness for additional cold rolling in excess of 20 per cent is less marked than is the increase in tensile strength. This makes it rather difficult to identify the hard, extra-hard, and spring tempers on the basis of hardness tests alone.

Like the tensile strength, the proportional limit values for the 18 per cent nickel alloy increase with increasing amounts of cold reduction. However, in the case of the standard 12 per cent nickel alloy, the proportional limit appears to reach a maximum in the half-hard temper, and additional amounts of cold rolling seem to cause little or no increase. In the case of the high-copper 12 and 10 per cent nickel alloys cold working in excess of 37 per cent (hard temper) actually seems to be deleterious in that somewhat lower values are observed for the proportional limits of extra-hard and spring temper material. This observation should be confirmed by additional tests.

The yield strengths of the 18 per cent nickel alloys show an increase with increasing amounts of cold working comparable to that observed in the tensile values. This increase is less marked in the case of the standard 12 per cent nickel alloy, while the yield strength of the high-copper 12 per cent nickel alloy appears to reach a maximum for amounts of cold working intermediate between those corresponding to half-hard and hard tempers. In the case of the 10 per cent alloy the yield strength, like the proportional limit, falls off in the case of the harder tempers.

The effect of cold rolling on the modulus of elasticity does not appear to follow any set pattern. For the 18 per cent nickel alloy, the modulus value falls off slightly with cold working and then increases to a maximum in the case of extra-hard and spring tempers. For the standard 12 per cent and the

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[5] Tentative Methods of Tension Testing of Metallic Materials (E 8 - 52 T), 1952 Book of ASTM Standards, Part 1, p. 1389, Part 2, p. 1208.

TABLE II.—MECHANICAL PROPERTIES OF ALLOY NO. 4 (18 PER CENT NICKEL) NICKEL SILVER STRIP IN ACCORDANCE WITH ASTM TENTATIVE SPECIFICATION B 122 – 52 T.

	Nominal Thickness, in.	Grain Direction	Per cent Reduction by Cold Rolling	Tensile Strength, psi	Proportional Limit, psi	Yield Strength, psi		Elongation, in 2 in., per cent	Modulus of Elasticity, psi	Rockwell 30T Hardness	Fatigue Strength, psi, at 10^8 Cycles of Reversed Stress
						0.01 per cent Offset	0.2 per cent Offset				
				ANNEALED TEMPER							
	0.005	Longitudinal	0	69 400	...	...	...	34.0	...	69.4[a]	...
	0.006	Longitudinal	0	66 200	...	...	...	33.0	...	60.9[a]	...
	0.008	Longitudinal	0	67 000	...	...	...	38.0	...	53.1[a]	...
	0.010	Longitudinal	0	65 300	...	...	...	39.0	...	54.1[a]	...
	0.0126	Longitudinal	0	64 500	...	...	...	34.0	...	56.4[a]	...
	0.016	Longitudinal	0	65 200	...	...	...	41.0	...	54.9[a]	...
	0.020	Longitudinal	0	66 900	...	...	...	42.0	...	56.8[a]	...
	0.020	Longitudinal	0	66 900	...	...	...	42.0	20.0 × 10^6	57.0[b]	17 500
	0.020	Longitudinal	0	62 200	12 300	...	...	45.5	18.1	...	16 000
	0.020	Longitudinal	0	60 500	...	...	...	48.0	...	51.5[a]	16 500
		45 deg	0	62 800	15 400	...	...	49.0	...	...	17 500
		Transverse	0	60 400	...	...	...	48.0	...	...	14 000
	0.020	Longitudinal	0	62 900	...	19 200	26 000	45.0	19.6	49.0	16 000
		45 deg	0	61 700	17 500	21 700	25 800	47.0	19.4	...	...
		Transverse	0	62 200	17 500	22 400	26 100	47.0	20.7	...	...
	0.025	Longitudinal	0	74 600	...	...	...	35.5	...	61.9[a]	...
	0.032	Longitudinal	0	67 600	...	...	...	44.0	...	54.1[a]	...
	0.040	Longitudinal	0	65 300	...	...	...	45.5	...	50.1[a]	...
	0.051	Longitudinal	0	65 100	...	...	...	47.0	...	50.6[a]	...
	0.064	Longitudinal	0	66 100	...	...	...	45.5	...	52.1[a]	...
				HALF-HARD TEMPER							
Specification Limits →	...	Longitudinal	20.7[c]	78 000 to 95 000		...	...	...	...	71 to 78	...
	0.005	Longitudinal	23.0	83 200	...	...	...	8.5	...	71.2[a]	...
	0.006	Longitudinal	23.5	86 200	...	...	...	6.5	...	67.4[a]	...
	0.010	Longitudinal	18.4	77 500	...	...	...	14.5	...	70.6[a]	...
	0.0126	Longitudinal	20.3	83 300	...	...	...	12.5	...	73.4[a]	...
	0.016	Longitudinal	21.9	83 000	...	...	...	11.5	...	74.2[a]	...
	0.020	Longitudinal	19.4	94 900	...	...	...	8.5	...	76.6[a]	...
	0.025	Longitudinal	16.5	80 600	...	...	...	19.5	...	72.4[a]	...
	0.025	Longitudinal	20.7	79 300	35 700	43 100	63 900	22.3	18.2	72.8	23 000
	0.032	Longitudinal	19.9	80 700	...	...	...	16.5	...	73.5[a]	...
	0.032	Longitudinal	20.7	91 600	41 500	51 200	85 200	9.4	19.2	78.3	27 000

	0.040	Longitudinal	19.4	81 100	...	...	...	16.0	...	73.6^a	...
	0.051	Longitudinal	21.6	85 600	...	...	...	12.0	...	75.8^a	...
	0.064	Longitudinal	22.6	81 300	...	...	...	13.0	...	74.8^a	...
				HARD TEMPER							
Specification Limits →	...	Longitudinal	37.2^c	92 000 to 107 000	...	...	...	...	...	76 to 80	...
	0.005	Longitudinal	35.3	96 500	...	...	...	1.5	...	71.3^a	...
	0.006	Longitudinal	40.0	96 300	...	...	...	2.0	...	69.5^a	...
	0.010	Longitudinal	35.9	95 600	...	...	...	2.5	...	75.6^a	...
	0.0126	Longitudinal	38.5	102 800	...	...	...	1.5	...	77.7^a	...
	0.020	Longitudinal	34.9	98 700	...	...	...	2.0	...	76.9^a	...
	0.020	Longitudinal	37.8	98 700	...	...	...	2.0	...	77.5^b	...
	0.020	Longitudinal	37.2^c	95 400	...	...	...	1.5	...	76.0^b	20 500
		45 deg		94 400	44 000	...	...	2.4	18.0	...	22 000
		Transverse		93 200	...	...	...	5.3	...	...	18 500
	0.020	Longitudinal	37.2^c	101 500	43 600	63 700	100 400	1.0	20.4	77.5^a	21 000
		45 deg		97 600	41 800	59 000	88 600	2.5	17.6	...	...
		Transverse		101 400	48 300	60 700	92 200	2.3	20.6	...	...
	0.025	Longitudinal	37.8	98 700	...	...	...	2.0	...	77.2^a	...
	0.032	Longitudinal	35.4	96 300	...	...	...	3.0	...	76.9^a	...
	0.040	Longitudinal	37.6	97 400	...	...	...	4.0	...	76.2^a	...
	0.051	Longitudinal	40.1	97 400	...	...	...	3.0	...	78.4^a	...
	0.064	Longitudinal	37.2	93 400	...	...	...	5.0	...	77.9^a	...
				EXTRA-HARD TEMPER							
Specification Limits →	...	Longitudinal	50.0^c	102 000 to 115 000	...	...	...	...	...	79 to 82	...
	0.005	Longitudinal	45.0	102 700	...	...	...	1.0	...	72.1^a	...
	0.008	Longitudinal	49.1	102 400	...	...	...	1.0	...	78.2^a	...
	0.010	Longitudinal	46.1	107 500	...	...	...	1.0	...	78.5^a	...
	0.016	Longitudinal	46.3	106 600	...	...	...	1.5	...	78.2^a	...
	0.020	Longitudinal	48.3	107 000	...	...	...	1.0	...	78.2^a	...
	0.020	Longitudinal	49.1	102 200	48 300	...	...	1.2	20.3	...	21 000
	0.020^d	Longitudinal	50.0^c	106 600	...	...	...	...	...	...	25 500
	0.020^e	Longitudinal	50.0^c	108 500	...	...	...	...	...	...	23 000
	0.020^f	Longitudinal	50.0^c	108 100	...	...	...	...	...	...	23 000

(Continued on pp. 234 and 235)

TABLE II.—*Continued.*

Nominal Thickness, in.	Grain Direction	Per cent Reduction by Cold Rolling	Tensile Strength, psi	Proportional Limit, psi	Yield Strength, psi		Elongation, in 2 in., per cent	Modulus of Elasticity, psi	Rockwell 30T Hardness	Fatigue Strength, psi, at 10⁸ Cycles of Reversed Stress
					0.01 per cent Offset	0.2 per cent Offset				
EXTRA-HARD TEMPER—*Continued*										
0.020	Longitudinal	50.0[c]	104 800	42 000	60 000	102 000	1.5	21.2	78.0	21 000
	45 deg		98 300	44 700	58 000	89 900	1.2	18.1	...	
0.020[e]	Longitudinal	50.0[c]	103 100	48 900	59 400	...	1.6	20.0	78.7	27 000
	45 deg		99 200	47 000	57 000	...	2.5	17.9	...	...
	Transverse		104 800	45 900	54 900	...	2.5	20.7	...	...
0.025	Longitudinal	49.6	107 000	...	...	...	1.5	...	79.5[a]	...
0.032	Longitudinal	51.4	107 200	...	...	...	2.0	...	78.8[a]	...
0.040	Longitudinal	50.9	103 600	...	...	...	2.5	...	78.9[a]	...
0.051	Longitudinal	51.3	104 500	...	...	...	3.0	...	80.3[a]	...
0.064	Longitudinal	47.8	103 400	...	...	...	3.0	...	80.0[a]	...
SPRING TEMPER										
Specification Limits → ...	Longitudinal	60.5[c]	108 000 to 120 000	...	...	...	...	...	80 (min)	...
0.006	Longitudinal	61.1	109 200	...	...	...	1.0	...	72.3[a]	...
0.008	Longitudinal	60.5	112 600	...	...	...	1.0	...	78.2[a]	...
0.010	Longitudinal	59.1	119 500	...	...	...	1.0	...	80.6[a]	...
0.0126	Longitudinal	58.4	111 500	...	...	...	1.0	...	79.4[a]	...
0.016	Longitudinal	60.2	112 600	...	...	...	1.0	...	79.4[a]	...
0.020	Longitudinal	58.8	113 400	50 000	...	...	1.0	19.5	...	22 500
0.020[g]	Longitudinal	60.5[c]	114 200	...	...	...	...	...	...	28 250
0.020[h]	Longitudinal	60.5[c]	117 200	...	...	...	...	...	...	26 500
0.020[f]	Longitudinal	60.5[c]	112 400	...	...	...	...	...	...	23 750
0.020	Longitudinal	60.5[c]	110 300	47 300	68 000	...	1.5	21.5	80.0[a]	22 500
	45 deg	60.5[c]	109 200	48 600	65 900	100 400	2.0	18.8	...	...
	Transverse	60.5[c]	115 600	57 800	71 400	107 300	2.0	21.5	...	...
0.020	Longitudinal	58.8	112 400	...	...	...	1.5	...	79.5[a]	...
0.025	Longitudinal	60.6	112 200	...	...	...	1.5	...	79.5[a]	...
0.032	Longitudinal	61.4	109 500	...	...	...	2.0	...	79.3[a]	...
0.040	Longitudinal	62.1	110 400	...	...	...	2.0	...	80.2[a]	...
0.051	Longitudinal	60.8[e]	111 400	...	...	...	3.0	...	81.4[a]	...
0.064	Longitudinal	58.8	108 600	...	...	...	3.5	...	80.9[a]	...

EXTRA-SPRING TEMPER										
0.005	Longitudinal	67.1	111 100	...	...	...	1.0	...	73.4[a]	...
0.006	Longitudinal	68.3	115 900	...	...	...	1.0	...	74.6[a]	...
0.008	Longitudinal	66.9	122 200	...	...	...	1.0	...	80.8[a]	...
0.010	Longitudinal	66.7	115 100	...	...	...	1.0	...	80.4[a]	...
0.0126	Longitudinal	68.0[c]	116 400	...	...	...	1.0	...	80.2[a]	...
0.016	Longitudinal	67.4	114 700	...	...	...	1.0	...	80.1[a]	...
0.020	Longitudinal	68.9	116 200	...	...	...	1.5	...	80.3[a]	...
0.020	Longitudinal	68.0	116 200	...	...	...	1.5	...	81.0[b]	21 500
0.020	Longitudinal	68.0[c]	117 700	...	...	...	1.2	...	80.7[b]	25 000
	45 deg		114 800	48 900	...	...	1.5	...	...	26 500
	Transverse		124 600	...	...	...	2.0	...	...	28 000
0.025	Longitudinal	68.7	113 500	...	...	...	2.0	...	80.0[a]	...
0.032	Longitudinal	67.8	113 600	...	...	...	2.0	...	80.4[a]	...
0.040	Longitudinal	66.8	115 000	...	...	...	2.5	...	81.4[a]	...
0.051	Longitudinal	67.6	114 500	...	...	...	3.0	...	81.9[a]	...
0.064	Longitudinal	68.3	114 300	...	...	...	3.8	...	81.5[a]	...

[a] 30T values were obtained by conversion from *B* readings.

[b] 30T values were obtained by conversion from *G* readings.

[c] Nominal reduction.

Note: The ready-to-finish grain size of the various materials was that which was in commercial use at the time the alloys were rolled except for the following which were:

[d] 0.017 mm
[e] 0.022 mm
[f] 0.090 mm
[g] 0.015 mm
[h] 0.020 mm

TABLE III.—MECHANICAL PROPERTIES OF ALLOY NO. 8 (12 PER CENT NICKEL) NICKEL SILVER STRIP IN ACCORDANCE WITH ASTM TENTATIVE SPECIFICATION B 122 - 52 T.

	Nominal Thickness, in.	Grain Direction	Per cent Reduction by Cold Rolling	Tensile Strength, psi	Proportional Limit, psi	Yield Strength, psi		Elongation, in 2 in., per cent	Modulus of Elasticity, psi	Rockwell 30T Hardness	Fatigue Strength, psi, at 10 Cycles of Reversed Stress
						0.01 per cent Offset	0.2 per cent Offset				
					ANNEALED TEMPER						
	0.020	Longitudinal	0	62 400	16 600	...	...	59	16.3 × 10⁶	47.0[a]	...
		45 deg		60 800	17 800	...	...	65	16.5	...	...
		Transverse		60 200	17 800	...	...	62	18.1	...	...
					QUARTER-HARD TEMPER						
Specification Limits →	...	Longitudinal	10.9[b]	65 000 to 81 000	...	...	...	...	...	57 to 74	...
	0.020	Longitudinal	10.9[b]	70 200	33 200	42 300	57 400	26.8	18.2	65.5[a]	...
		45 deg		65 100	29 400	35 200	49 800	34.3	17.2	...	...
		Transverse		66 500	29 300	34 700	50 900	32.7	18.3	...	...
	0.032	Longitudinal	10.9[b]	75 700	31 000	37 100	56 000	36.9	17.6	71.8	25 000
		45 deg		71 700	32 700	38 200	52 400	41.1	16.3	...	...
		Transverse		72 600	32 700	37 800	53 600	36.9	16.8	...	25 000
					HALF-HARD TEMPER						
Specification Limits →	...	Longitudinal	20.7[b]	75 000 to 91 000	...	...	...	...	...	69 to 77	...
	0.020	Longitudinal	20.7[b]	88 000	45 500	62 200	84 500	7.3	18.0	75.7	25 500
		45 deg		85 000	44 000	51 200	75 900	7.6	16.7	...	...
		Transverse		86 100	45 200	50 900	75 200	7.1	18.2	...	28 000
	0.025	Longitudinal	20.7[b]	81 700	49 900	51 100	76 100	13.4	17.2	74.9	27 000
		45 deg		76 400	39 200	46 400	67 200	12.9	16.0	...	...
		Transverse		79 600	39 700	45 800	68 200	20.4	17.3	...	27 000

	0.040	Longitudinal	20.7[b]	76 800	40 300	45 700	65 800	25.3	16.8	74.2	25 500
		45 deg		72 800	35 900	42 200	60 000	30.9	15.9	...	...
		Transverse		73 900	35 300	41 800	60 100	28.7	17.2	...	25 500
	0.080	Longitudinal	20.7[b]	83 400	45 400	56 500	74 700	17.0	17.7	75.3	...
		45 deg		78 400	45 400	52 700	69 200	16.6	16.7	...	...
		Transverse		80 400	44 400	52 400	70 800	14.2	17.7	...	...
					HARD TEMPER						
Specification Limits →	...	Longitudinal	37.2[b]	90 000 to 105 000	...	...	...	...	...	76 to 79	...
	0.020	Longitudinal	37.2[b]	96 100	47 300	62 800	93 900	2.0	17.1	77.7	27 000
		45 deg		90 900	41 700	52 200	81 500	3.4	15.6	...	...
		Transverse		92 500	45 700	56 800	82 800	3.9	17.3	...	26 650
	0.020	Longitudinal	37.2[b]	96 100	46 300	56 000	...	3.2	19.6	77.0[a]	...
		45 deg		90 200	46 200	54 500	...	6.2	15.9	...	...
		Transverse		93 000	46 900	57 400	...	5.4	18.9	...	...
					EXTRA-HARD TEMPER						
Specification Limits →	...	Longitudinal	50.0[b]	101 000 to 114 000	...	...	...	...	...	79 to 81	...
	0.012	Longitudinal	50.0[b]	110 000	50 800	61 800	105 900	1.1	16.8	78.4	...
		45 deg		104 500	48 500	61 600	94 700	1.9	15.8	...	...
		Transverse		106 100	49 700	62 300	95 300	2.3	17.0	...	...
	0.020	Longitudinal	50.0[b]	111 800	47 200	65 100	108 100	1.0	17.0	80.8	26 000
		45 deg		106 200	47 500	59 200	94 500	2.5	15.7	...	...
		Transverse		108 300	49 200	62 100	96 200	2.4	17.8	...	32 000
	0.020	Longitudinal	50.0[b]	107 600	53 800	71 100	105 600	2.0	18.2	78.0[a]	23 000
		45 deg		102 600	50 100	60 200	93 000	3.0	16.3	...	...
		Transverse		107 400	51 300	63 900	96 500	3.0	18.9	...	...
	0.022	Longitudinal	50.0[b]	106 800	43 200	58 200	102 600	1.5	17.0	80.0	26 000
		45 deg		100 300	43 500	54 200	89 400	2.4	15.4	...	...
		Transverse		102 400	45 000	56 200	90 900	2.6	17.1	...	27 000

(Continued on p. 238)

TABLE III.—*Continued.*

Nominal Thickness, In.	Grain Direction	Per cent Reduction by Cold Rolling	Tensile Strength, psi	Proportional Limit, psi	Yield Strength, psi		Elongation, in 2 in., per cent	Modulus of Elasticity, psi	Rockwell 30T Hardness	Fatigue Strength, psi, at 10^8 Cycles of Reversed Stress
					0.01 per cent Offset	0.2 per cent Offset				
					EXTRA-HARD TEMPER—*Continued*					
0.028	Longitudinal	50.0[b]	111 800	41 700	58 600	106 000	2.0	16.6	82.4	...
	45 deg		106 300	39 500	56 000	92 600	2.5	15.3	...	...
	Transverse		110 700	44 000	60 600	96 200	2.6	17.6	...	...
0.030	Longitudinal	50.0[b]	109 600	40 800	57 600	105 200	2.0	17.2	82.0	...
	45 deg		104 500	45 600	62 200	92 700	3.1	15.4	...	...
	Transverse		108 700	40 300	57 100	96 000	3.1	18.0	...	...
0.032	Longitudinal	50.0[b]	110 500	39 300	59 600	104 300	2.0	16.7	81.6	26 500
	45 deg		106 100	37 000	55 800	94 000	2.9	15.5	...	...
	Transverse		108 800	40 700	59 600	96 100	3.0	18.1	...	31 600
0.057	Longitudinal	50.0[b]	115 100	43 500	57 500	104 900	3.5	16.6	82.1	...
	45 deg		110 200	46 100	61 700	97 500	4.4	15.0	...	...
	Transverse		114 900	47 800	67 500	103 100	4.0	17.4	...	...
0.080	Longitudinal	50.0[b]	106 500	47 700	59 100	96 700	4.5	17.5	80.3	...
	45 deg		101 900	50 700	63 000	91 600	6.2	15.4	...	...
	Transverse		108 100	50 400	63 400	97 100	6.0	17.8	...	...
					SPRING TEMPER					
Specification Limits → ...	Longitudinal		109 000 to 122 000	...	...	...	...	...	80 (min)	...
0.022	Longitudinal	60.5[b]	118 800	40 800	59 000	113 100	1.5	16.7	82.8	31 000
	45 deg		114 700	41 500	53 500	99 800	2.5	15.7	...	...
	Transverse		117 600	45 800	60 700	102 300	2.4	17.8	...	37 000
0.020	Longitudinal	60.5[b]	113 200	57 100	72 400	110 400	2.0	18.3	80.0[a]	...
	45 deg		110 400	52 600	65 100	99 200	2.0	16.0	...	...
	Transverse		114 900	55 100	68 000	102 100	2.3	18.2	...	...

[a] 30T values were obtained by conversion from *B* readings.

[b] Nominal reduction.

TABLE IV.—MECHANICAL PROPERTIES OF 60 PER CENT COPPER, 12 PER CENT NICKEL, NICKEL SILVER STRIP.

Nominal Thickness, in.	Grain Direction	Per cent Reduction by Cold Rolling	Tensile Strength, psi	Proportional Limit, psi	Yield Strength, psi		Elongation, in 2 in., per cent	Modulus of Elasticity, psi	Rockwell 30T Hardness	Fatigue Strength, psi at 10^8 Cycles of Reversed Stress
					0.01 per cent Offset	0.2 per cent Offset				
	Quarter-Hard Temper									
0.043	Longitudinal	10.9[a]	85 100	43 000	57 400	82 200	7.0	17.9×10^6	76.1	25 000
	45 deg		80 700	31 400	47 100	72 500	8.6	16.8	...	...
	Transverse		84 700	30 500	48 400	75 000	7.7	18.4	...	...
0.034	Longitudinal	10.9[a]	73 100	34 700	37 600	56 100	28.3	17.6	70.6	...
	45 deg		69 900	31 900	36 600	51 700	32.8	16.7	...	...
	Transverse		71 000	32 000	37 000	52 600	33.2	17.5	...	...
	Half-Hard Temper									
0.036	Longitudinal	20.7[a]	96 700	50 500	65 400	94 700	2.5	17.2	78.4	26 000
	45 deg		92 500	34 400	49 200	83 400	4.1	16.3	...	...
	Transverse		96 100	36 700	52 700	85 800	4.3	18.5	...	...
	Hard Temper									
0.032	Longitudinal	37.2[a]	102 700	51 800	65 100	100 500	2.5	17.6	79.3	28 000
	45 deg		99 400	39 600	52 900	88 700	3.0	16.3	...	...
	Transverse		102 900	44 800	54 600	90 800	2.5	18.7	...	...
	Extra-Hard Temper									
0.029	Longitudinal	50.0[a]	102 300	51 600	60 900	99 500	1.9	17.1	79.7	32 000
	45 deg		101 800	41 900	53 400	90 400	3.0	16.4	...	...
	Transverse		106 100	40 000	53 100	93 600	3.2	18.8	...	...
0.030	Longitudinal	50.0[a]	104 500	44 000	54 500	101 300	2.0	17.9	80.9	...
	45 deg		100 700	45 900	54 400	89 300	2.7	16.1	...	...
	Transverse		105 500	48 700	59 000	93 600	3.4	18.3	...	...
	Spring Temper									
0.024	Longitudinal	60.5[a]	113 300	47 300	58 800	107 000	1.5	16.7	81.7	...
	45 deg		111 800	54 300	62 700	98 000	2.2	16.0	...	...
	Transverse		115 400	56 800	65 400	101 000	2.1	17.9	...	...

[a] Nominal reduction

TABLE V.—MECHANICAL PROPERTIES OF 60 PER CENT COPPER, 10 PER CENT NICKEL, NICKEL SILVER STRIP.

Nominal Thickness, in.	Grain Direction	Per cent Reduction by Cold Rolling	Tensile Strength, psi	Proportional Limit, psi	Yield Strength, psi		Elongation, in 2 in., per cent	Modulus of Elasticity, psi	Rockwell 30T Hardness	Fatigue Strength, psi at 10^8 Cycles of Reversed Stress
					0.01 per cent Offset	0.2 per cent Offset				
	ANNEALED TEMPER									
0.032	Longitudinal	0	61 000	14 000	19 000	26 000	54.0	17.4 × 10^6	49.0	20 000
0.064	Longitudinal	0	60 500	13 200	18 500	27 200	53.7	15.3	51.4	...
	45 deg		61 100	20 700	23 800	28 800	61.2	16.0	...	...
	Transverse		60 200	19 800	23 100	28 300	57.8	17.7	...	...
0.080	Longitudinal	0	64 800	18 400	24 400	32 300	53.1	15.8	57.7	...
	45 deg		63 400	20 200	24 800	33 100	56.2	15.0	...	...
	Transverse		62 900	24 300	28 100	32 600	53.8	16.2	...	...
	QUARTER-HARD TEMPER									
0.028	Longitudinal	10.9[a]	69 000	32 000	37 000	53 000	37.0	16.5	68.0	27 000
0.057	Longitudinal	13.0	68 700	25 200	28 800	45 000	38.0	17.2	68.7	...
	45 deg		67 500	30 800	36 700	51 600	43.9	16.3	...	...
	Transverse		67 500	30 900	36 400	51 600	38.0	16.4	...	...
0.072	Longitudinal	9.5	71 700	30 000	36 700	53 300	39.9	16.2	68.7	...
	45 deg		68 100	32 100	36 800	50 100	40.7	16.7	...	...
	Transverse		68 400	31 600	36 700	50 300	36.8	16.7	...	...
	HALF-HARD TEMPER									
0.025	Longitudinal	17.2	76 000	40 000	50 000	69 000	20.0	16.7	73.0	24 000
0.051	Longitudinal	20.5	74 900	37 500	37 900	66 200	23.5	17.2	72.8	...
			71 700	37 200	43 700	62 700	27.4	15.3	...	...
			72 400	37 000	43 400	62 600	19.2	16.9	...	...
0.064	Longitudinal	18.8	78 400	35 200	47 500	68 000	26.1	17.5	72.7	...
			72 700	35 700	42 600	61 000	27.2	16.2	...	...
			74 000	33 300	41 500	61 400	26.3	17.0	...	...
	HARD TEMPER									
0.022	Longitudinal	30.9	88 000	48 000	60 000	86 000	3.5	17.3	76.0	28 000
0.040	Longitudinal	39.5	93 500	44 600	53 800	89 900	4.1	16.9	78.9	...
	45 deg		88 800	41 300	53 900	80 600	5.6	15.1	...	...
	Transverse		91 200	44 500	54 800	82 900	5.1	17.4	...	...
0.051	Longitudinal	39.5	99 800	40 600	52 300	94 500	4.1	17.2	79.2	...
	45 deg		95 000	38 700	50 600	85 100	6.1	15.8	...	...
	Transverse		99 100	44 600	54 700	87 500	5.1	17.4	...	...

TABLE V.—*Concluded.*

Nominal Thickness, in.	Grain Direction	Per cent Reduction by Cold Rolling	Tensile Strength, psi	Proportional Limit, psi	Yield Strength, psi		Elongation, in 2 in., per cent	Modulus of Elasticity, psi	Rockwell 30T Hardness	Fatigue Strength, psi at 10^8 Cycles of Reversed Stress
					0.01 per cent Offset	0.2 per cent Offset				
					Extra-Hard Temper					
0.016	Longitudinal	43.5	104 800	48 300	66 900	102 300	1.0	16.7	78.5	...
	45 deg		103 400	50 100	58 300	91 400	1.6	15.3	...	...
	Transverse		106 200	45 500	54 200	91 600	2.4	17.2	...	...
0.032	Longitudinal	48.9	104 100	43 000	54 700	100 200	2.5	16.5	80.5	...
	45 deg		99 800	39 800	55 900	88 800	2.9	14.7	...	...
	Transverse		104 500	41 400	55 100	91 200	2.5	17.6	...	...
0.040	Longitudinal	52.1	110 200	41 700	57 200	102 900	2.5	16.4	81.2	...
	45 deg		106 400	38 900	55 100	93 900	3.5	15.7	...	...
	Transverse		110 500	46 100	61 800	96 300	3.6	17.6	...	...
					Spring Temper					
0.013	Longitudinal	56.5	109 800	48 300	58 200	104 100	0.6	16.6	79.4	...
	45 deg		108 600	44 600	55 100	93 400	0.8	15.4	...	...
	Transverse		112 300	50 900	60 900	96 500	0.9	17.2	...	...
0.025	Longitudinal	61.5	113 800	42 000	55 300	106 800	2.0	15.9	81.6	...
	45 deg		113 500	39 100	58 000	92 200	2.5	15.3	...	...
	Transverse		116 800	44 900	59 700	100 000	2.9	17.9	...	...
0.032	Longitudinal	62.3	116 200	40 000	59 200	108 800	2.0	16.2	82.3	...
	45 deg		115 400	39 000	51 500	98 900	3.0	15.7	...	...
	Transverse		121 100	47 400	62 000	104 000	3.0	17.6	...	...

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[a] Nominal reduction.

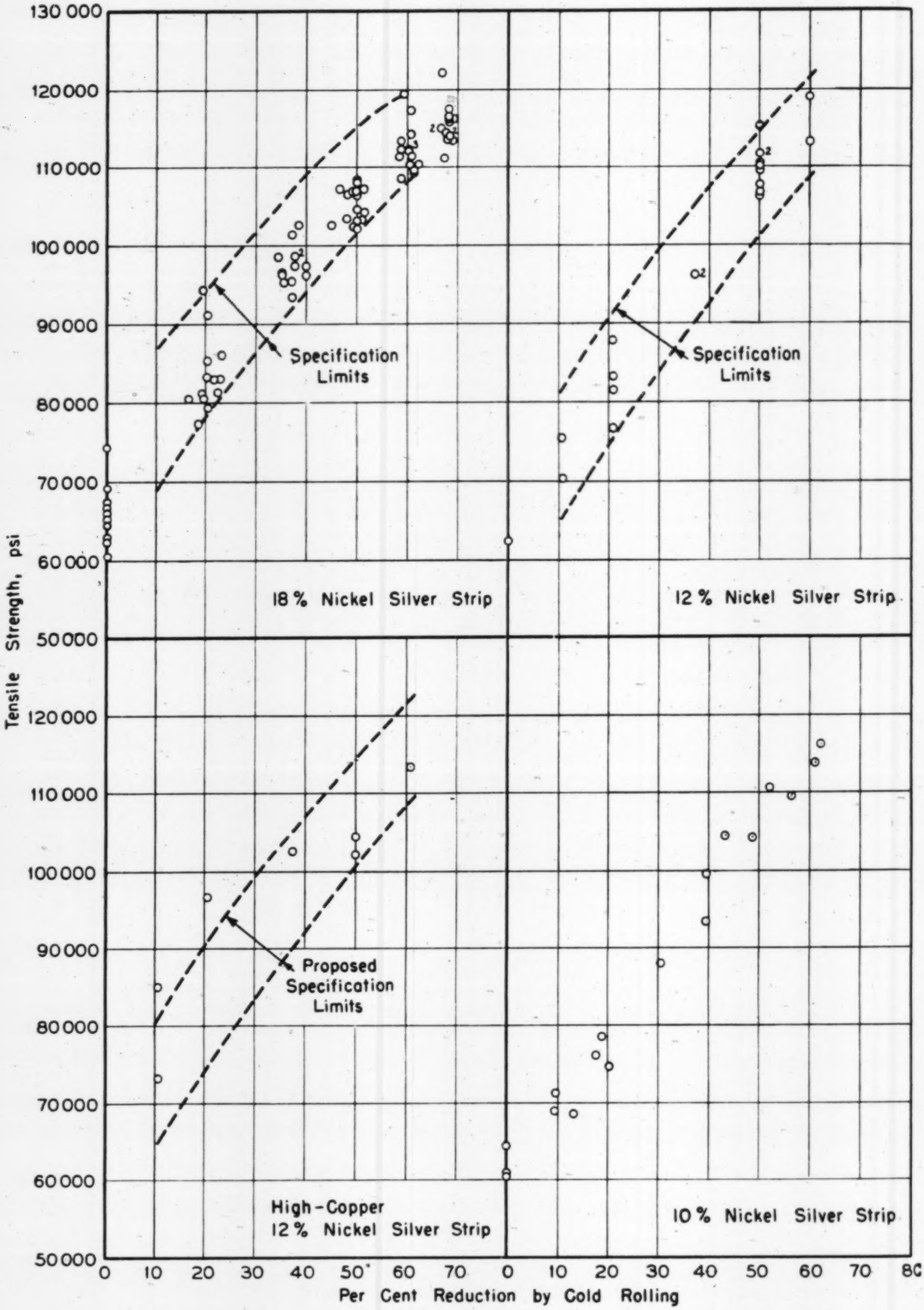

FIG. 1.—Relation Between Tensile Strength and per cent Reduction by Cold Rolling.

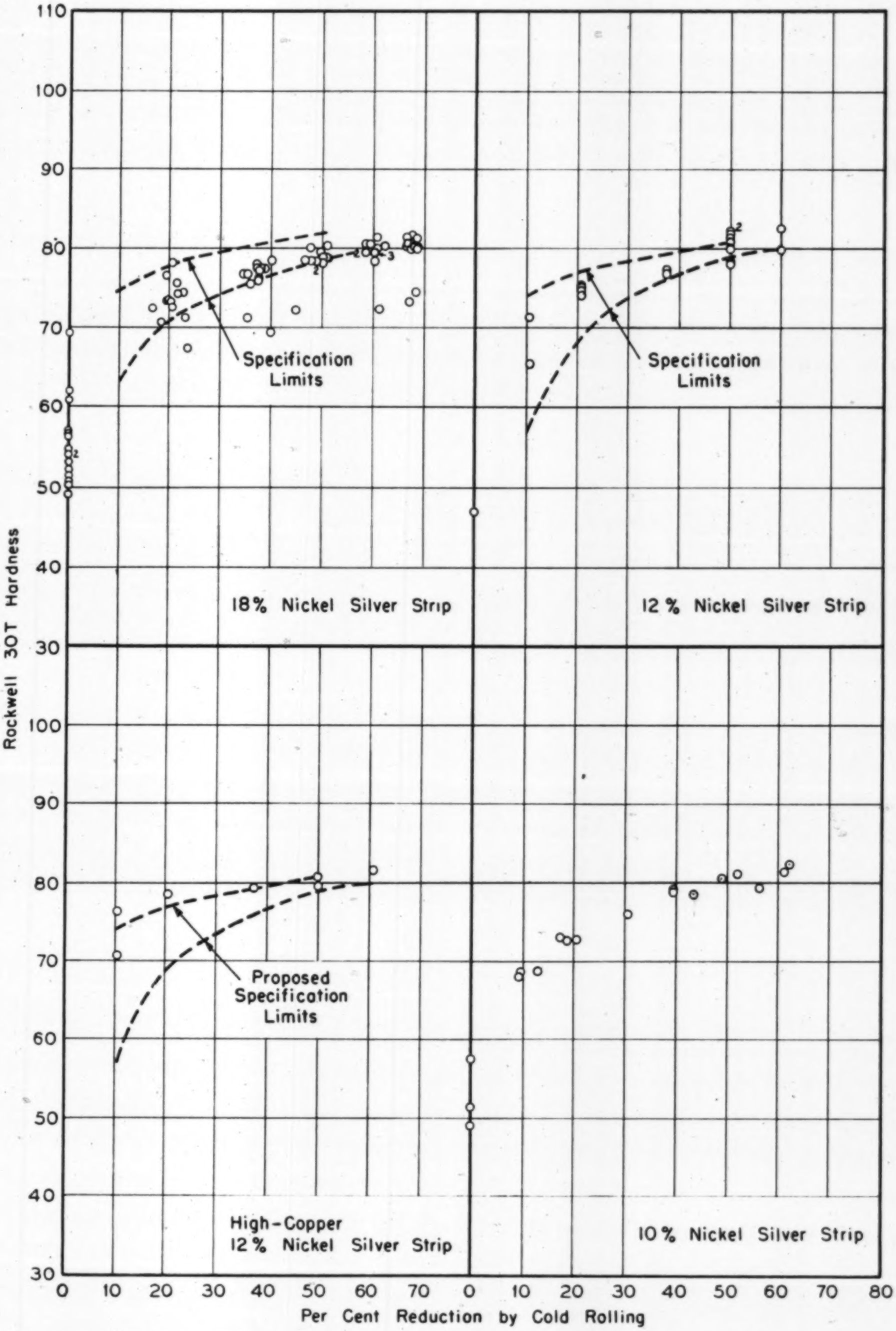

FIG. 2.—Relation Between Rockwell 30T Hardness and per cent Reduction by Cold Rolling.

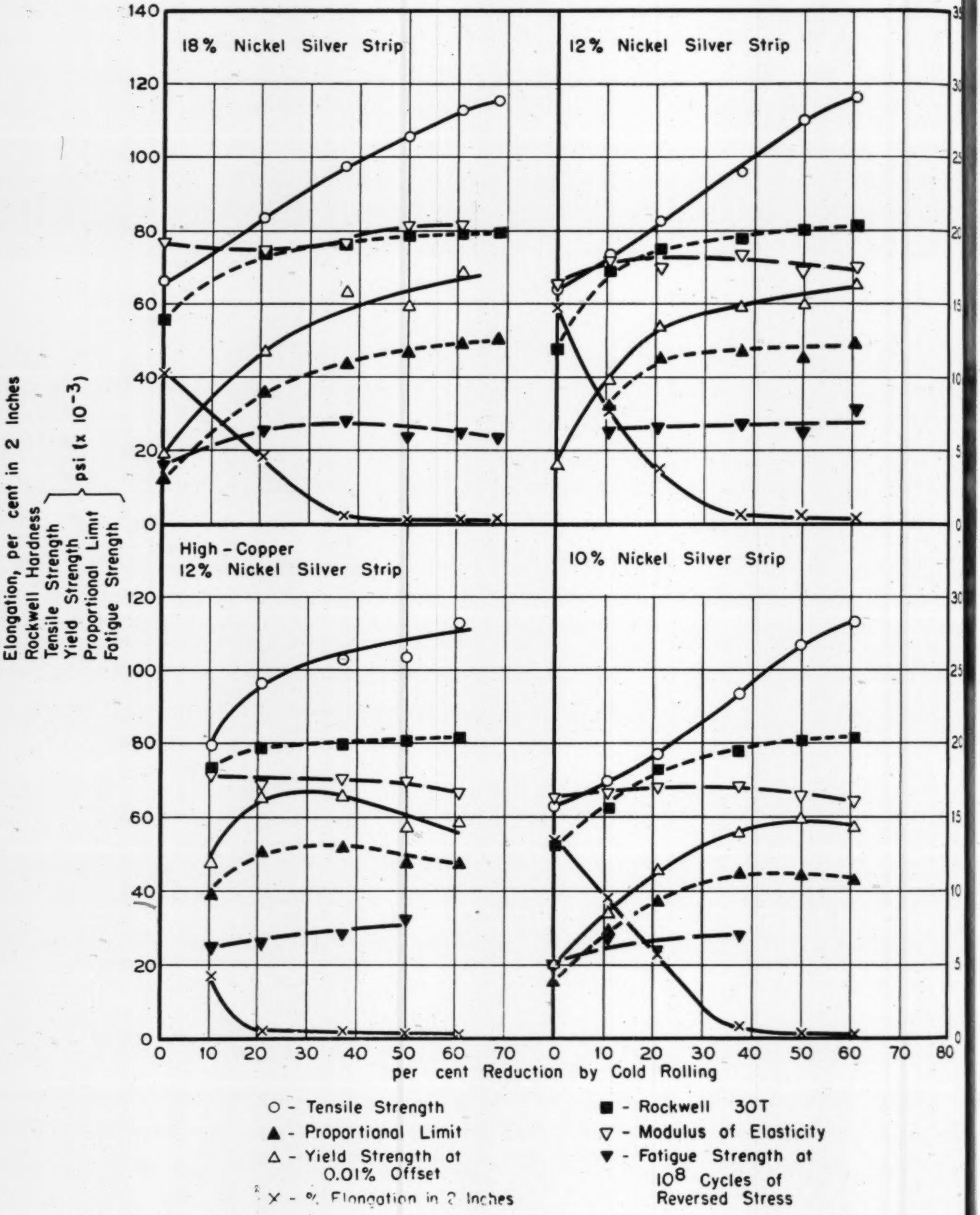

FIG. 3.—Effect of Cold Rolling on the Average Mechanical Properties of Some Nickel Silver Alloy Strips.

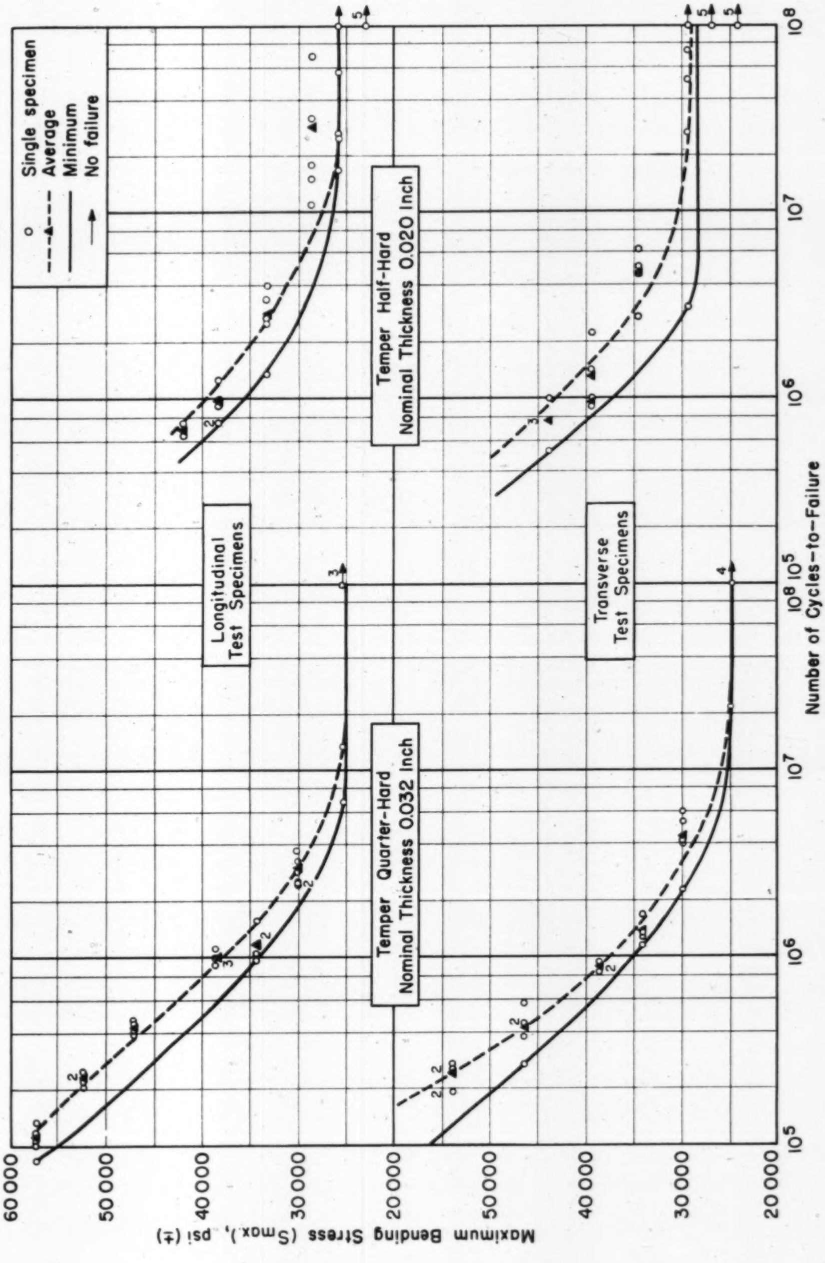

FIG. 4.—Bending Fatigue Properties of 12 per cent Nickel, Nickel Silver Strip.

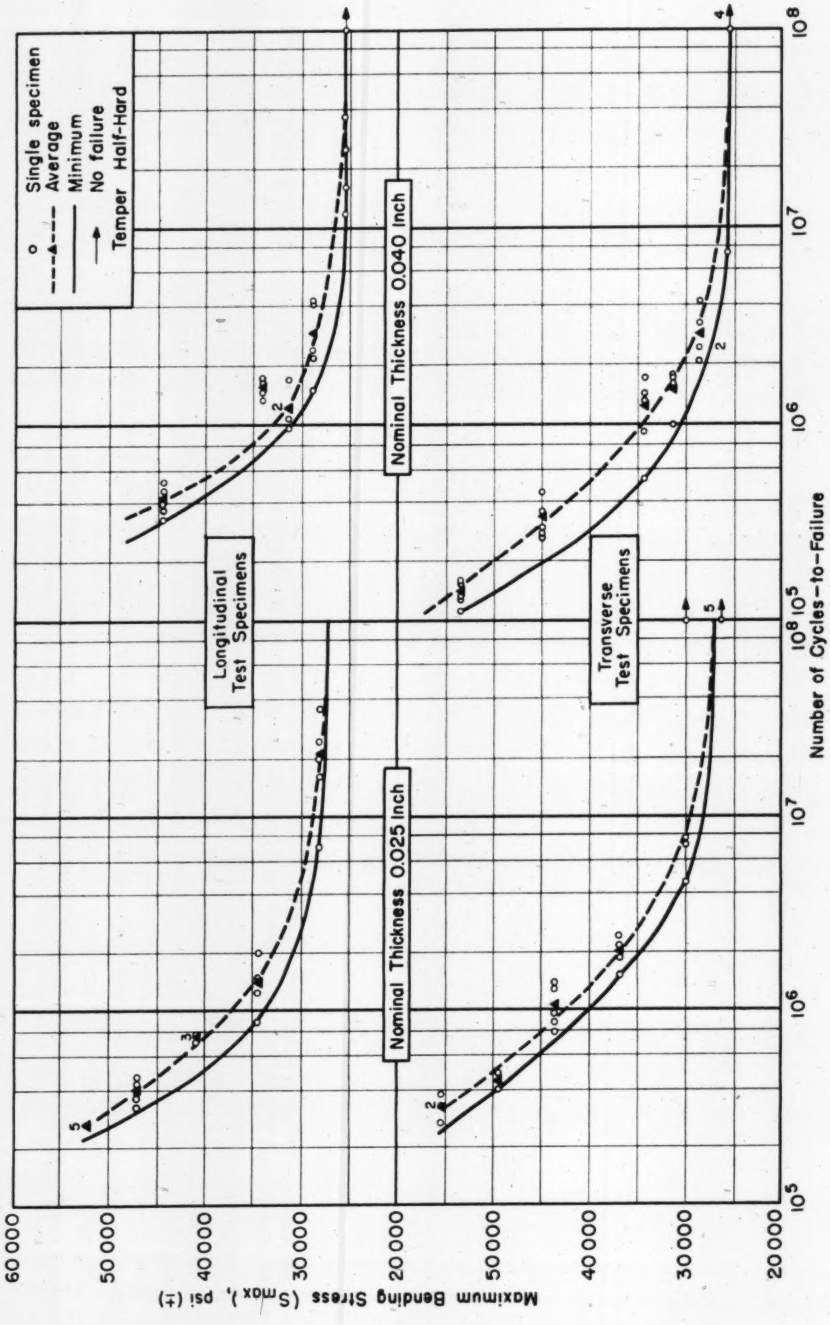

FIG. 5.—Bending Fatigue Properties of 12 per cent Nickel. Nickel Silver Strip.

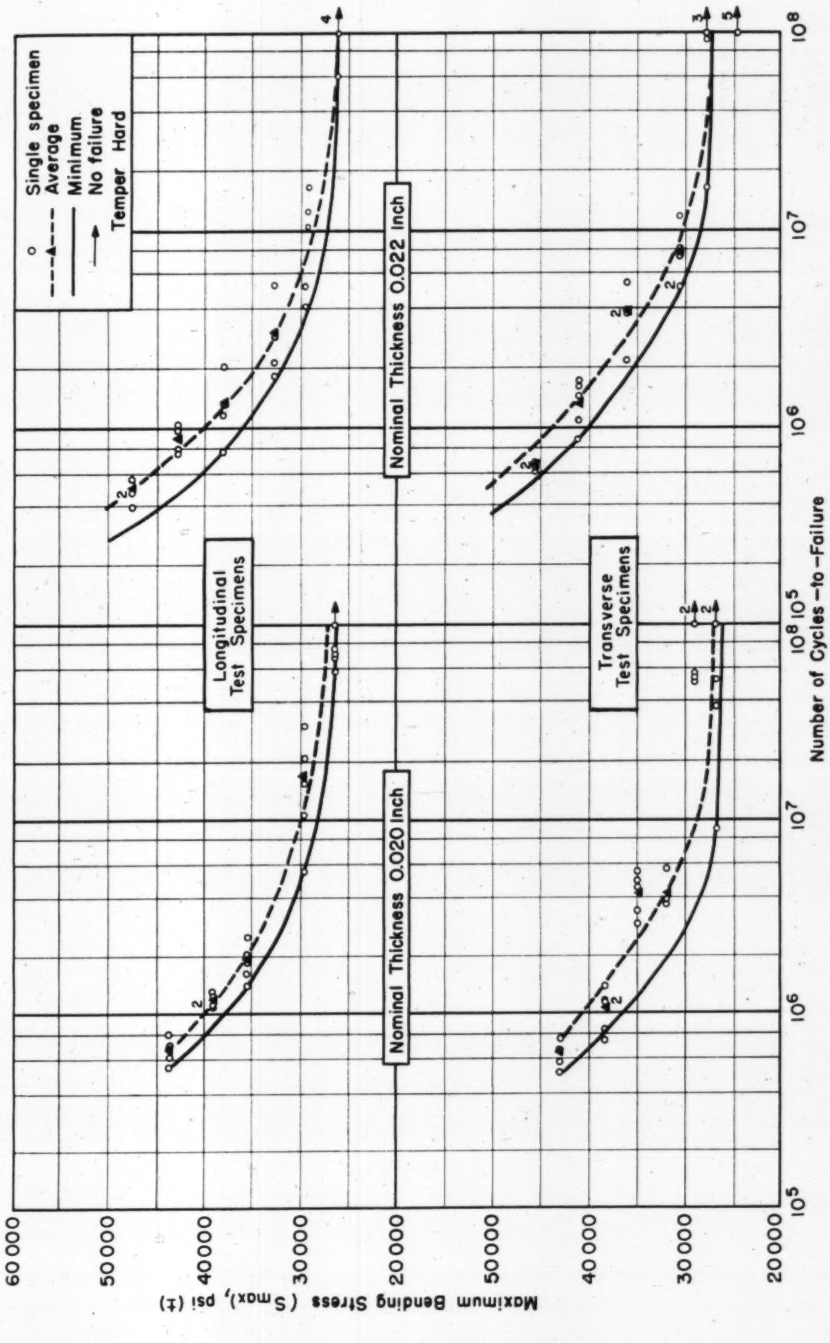

FIG. 6.—Bending Fatigue Properties of 12 per cent Nickel, Nickel Silver Strip.

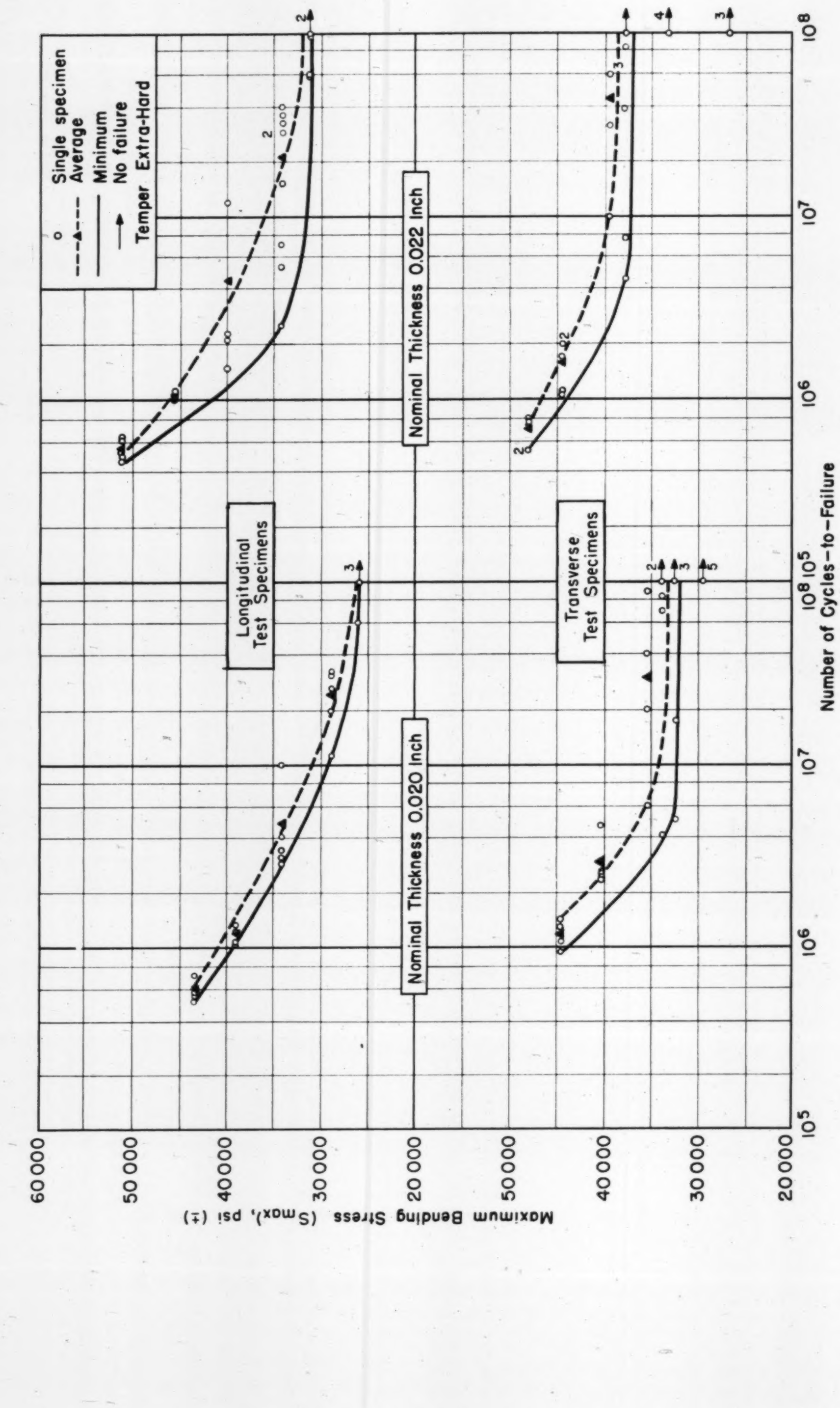

FIG. 7.—Bending Fatigue Properties of 12 per cent Nickel, Nickel Silver Strip.

high-copper 10 per cent nickel alloys the maximum value of modulus is reached in the case of the half-hard and hard tempers, while for the high-copper 12 per cent nickel alloys the peak in modulus values between half-hard and hard tempers is absent, but the decrease for the harder tempers is evident. Here again additional studies appear to be warranted.

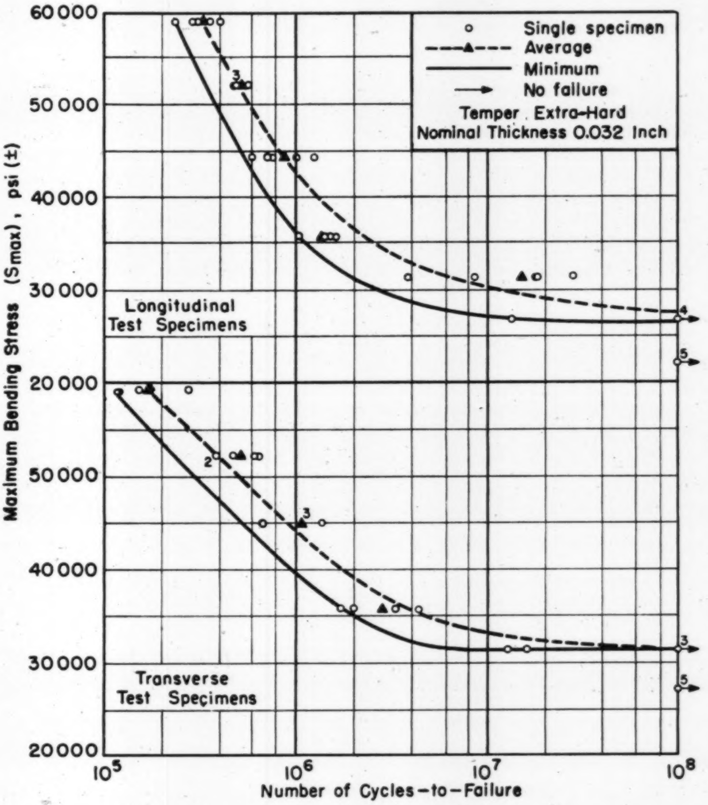

FIG. 8.—Bending Fatigue Properties of 12 per cent Nickel, Nickel Silver Strip.

As expected, the elongation for all four alloys decreases with increasing amounts of cold rolling. It should be noted that the high-copper 12 per cent nickel alloy has somewhat lower elongation for the half-hard temper than do the other three alloys. The elongation values of the harder tempers (hard, extra-hard and spring) are not substantially different.

Data on the fatigue characteristics of the 18 per cent alloys are given by Greenall and Gohn (2). Fatigue data on the standard 12 per cent nickel alloy are given in Figs. 4 to 8 in the form of *S-N* diagrams. Similar data for the high-copper 12 per cent nickel alloy are given in Fig. 9, while Fig. 10 shows the results of fatigue tests on the 10 per cent nickel alloy. The fatigue strengths at 10^8 cycles of reversed stress are given in Tables II to V, inclusive, for the four alloys studied.

The fatigue strengths of the various

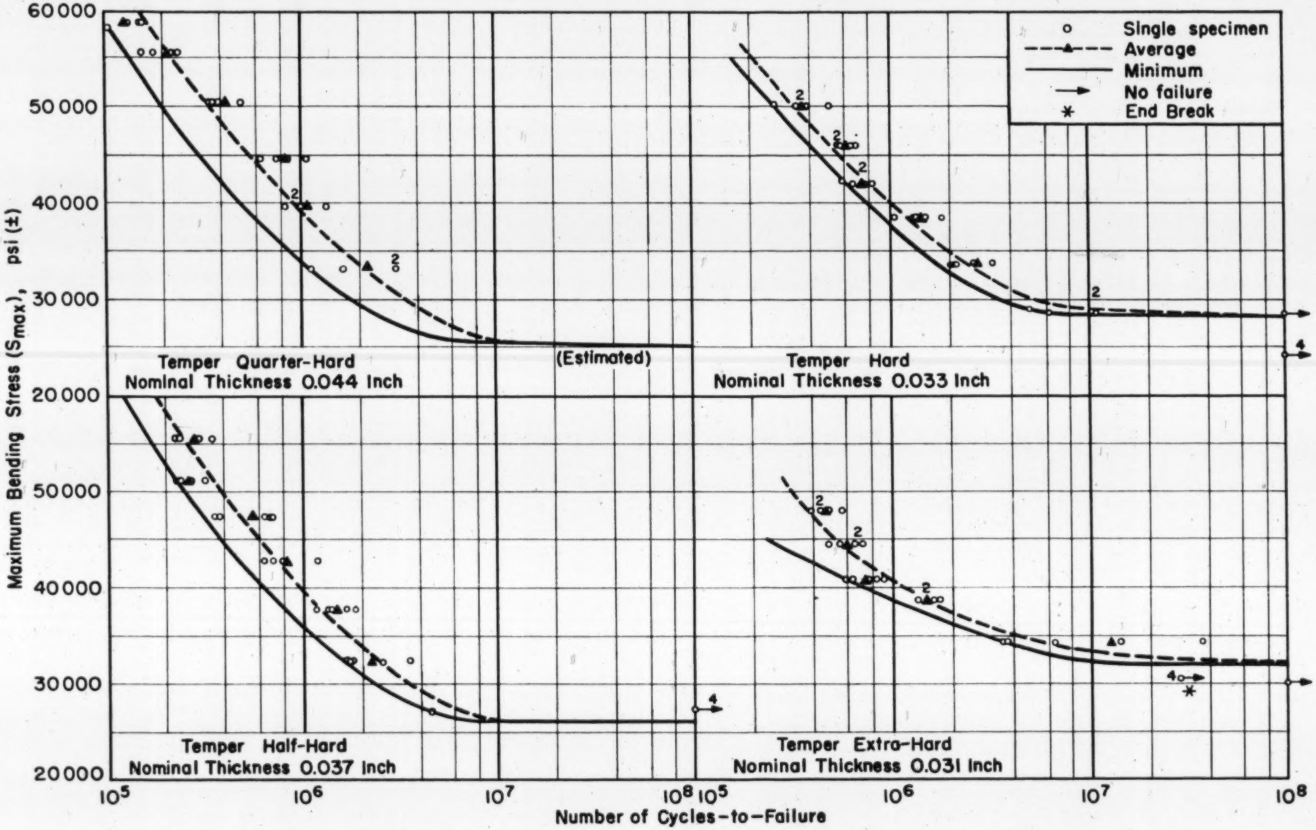

FIG. 9.—Bending Fatigue Properties of High-Copper 12 per cent Nickel, Nickel Silver Strip.

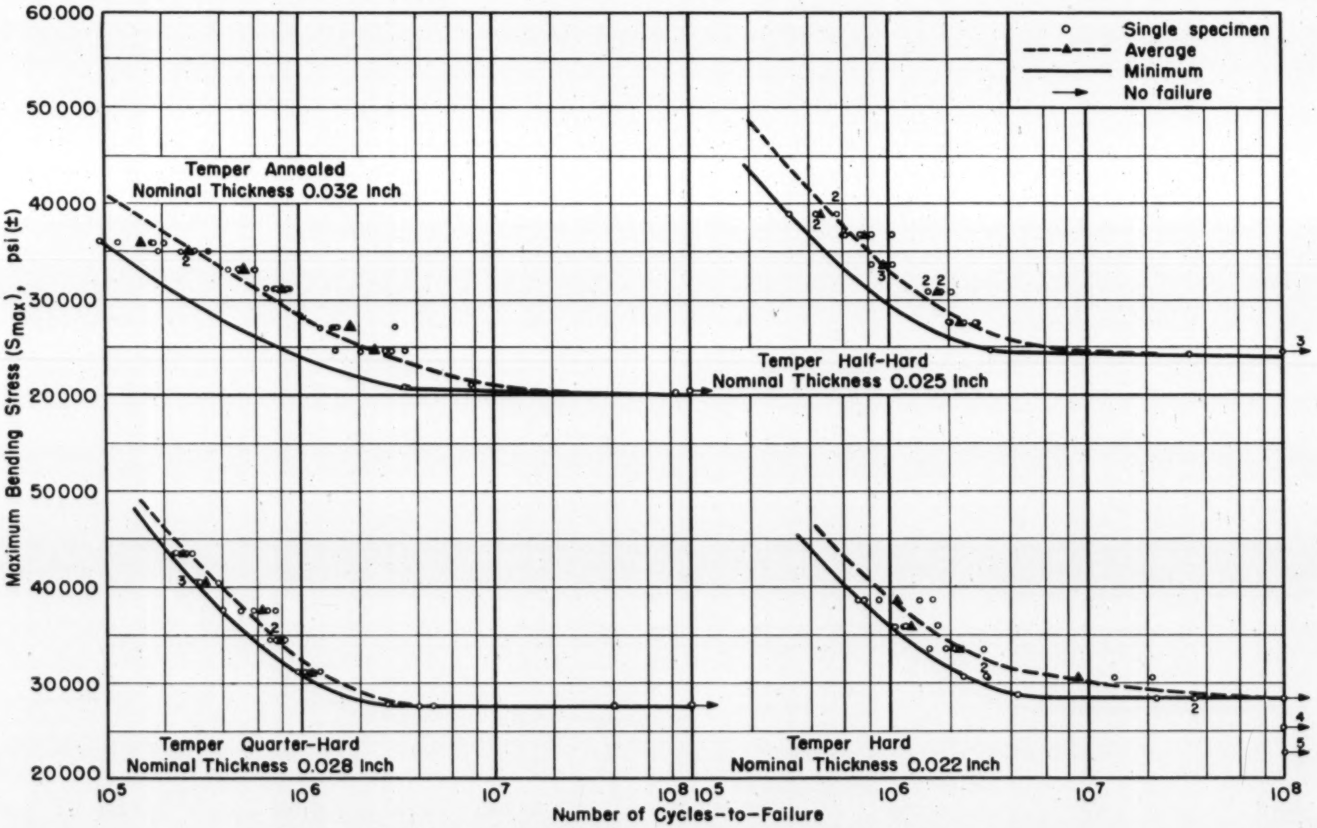

FIG. 10.—Bending Fatigue Properties of 10 per cent Nickel, Nickel Silver Strip.

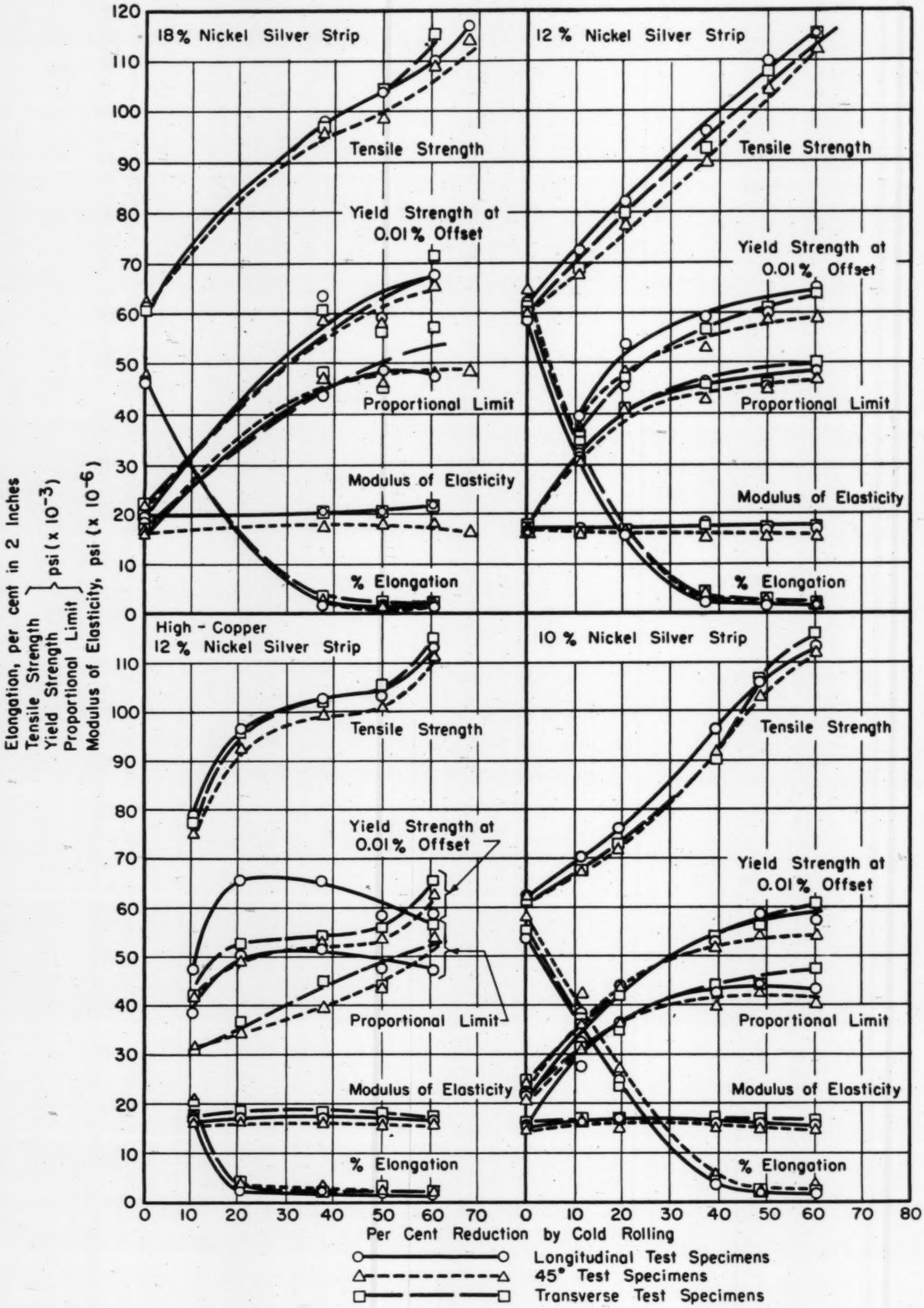

FIG. 11.—Effect of Grain Direction on Mechanical Properties of Nickel Silver Alloy Strips.

alloys studied vary somewhat with cold working. In the case of the 18 per cent nickel alloy a peak is reached in the case of hard temper, after which the fatigue strength falls off somewhat. The fatigue strength of the standard 12 per cent nickel alloy appears to be but little affected by cold working in excess of 11 per cent, whereas the fatigue strengths of the high-copper 12 and 10 per cent nickel alloys are all improved slightly by additional amounts of cold rolling.

In the determination of the mechanical properties of non-ferrous strip and sheet, test specimens are generally taken longitudinal, that is, parallel to the direction of rolling. Such tests are usually explicitly called for or implied in the various specifications covering the inspection and control of nickel silver strip. However, manufacturing economies or engineering requirements frequently dictate that formed parts shall be blanked with the principal axis at an angle to the direction of rolling. For such applications the designer requires data showing the effect of grain direction on the mechanical properties. Some data of this type are included in Tables II to V, inclusive. While the data are probably too few to justify any hard-and-fast conclusions, some discussion of the trends shown by the data (see Figs. 11 and 12) may be helpful.

In the annealed tempers, there is no significant variation in tensile strength with changes in grain direction. However, as the amount of cold rolling increases the differences become more marked. For intermediate tempers (quarter-hard, half-hard, and hard) the tensile strength is usually greatest for longitudinal specimens and least for those taken at 45 deg to the direction of rolling. As the amount of cold working increases (for example, extra-hard, spring, and extra-spring tempers) the tensile strengths of the transverse specimens tend to become greater than those of longitudinal specimens, while the tensile strengths of those taken at 45 deg are the lowest for the three values of grain direction studied.

In the annealed tempers, the lowest values of proportional limit were observed in the longitudinal specimens. For intermediate tempers the proportional limits were greater for the longitudinal specimens than for those taken transverse or at 45 deg to the direction of rolling. For the harder tempers the highest values were generally observed in the case of the transverse tests; the lowest for the specimens taken at 45 deg. In general, maximum proportional limit values were reached with 37 to 50 per cent cold working, and little appears to be gained by additional amounts of cold working.

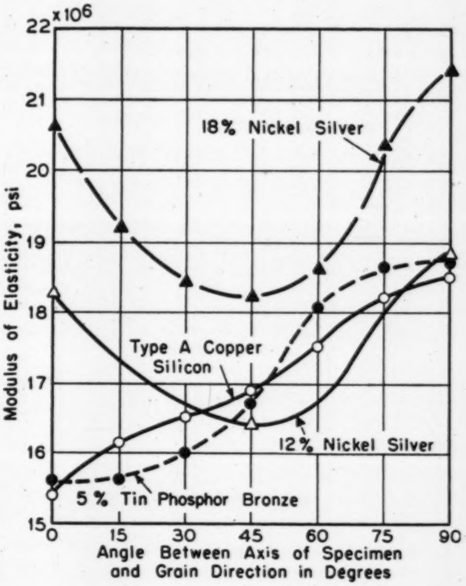

FIG. 12.—Effect of Grain Direction on the Modulus of Elasticity. Thickness Range 0.010 to 0.032 in.

The yield strength data—both for values corresponding to 0.01 and 0.2

TABLE VI.—COMPARISON OF AVERAGE MECHANICAL PROPERTIES OF FOUR NICKEL SILVER ALLOYS (STRIP).

Longitudinal Tests

	18 per cent Nickel Alloy	Standard 12 per cent Nickel Alloy	High Copper 12 per cent Nickel Alloy	High Copper 10 per cent Nickel Alloy
Annealed Temper				
Tensile strength, psi	66 000	62 400	...	62 100
Proportional limit, psi	12 300	16 600	...	15 200
Yield strength, psi:				
0.01 per cent offset	19 200	...	...	20 600
0.2 per cent offset	26 000	...	...	28 500
Elongation in 2 in., per cent	41.2	59.0	...	53.6
Modulus of Elasticity, psi	19 200 000	16 300 000	...	16 200 000
Rockwell 30T hardness	55.5	47.0	...	52.7
Fatigue strength at 10^8 cycles of reversed stress, psi	16 500	...	...	20 000
Quarter-Hard Temper				
Tensile strength, psi	...	73 000	79 100	69 800
Proportional limit, psi	...	32 100	38 800	29 100
Yield strength, psi:				
0.01 per cent offset	...	39 700	47 500	34 200
0.2 per cent offset	...	56 700	79 200	50 500
Elongation in 2 in., per cent	...	31.8	17.6	38.3
Modulus of elasticity, psi	...	17 900 000	17 800 000	16 600 000
Rockwell 30T hardness	...	68.6	73.4	62.5
Fatigue strength at 10^8 cycles of reversed stress, psi	...	25 000	25 000	27 000
Half-Hard Temper				
Tensile strength, psi	83 700	82 500	96 700	76 400
Proportional limit, psi	38 600	45 300	50 500	37 300
Yield strength, psi:				
0.01 per cent offset	47 200	53 900	65 400	45 100
0.2 per cent offset	76 200	75 300	94 700	67 700
Elongation in 2 in., per cent	13.1	15.8	2.5	23.2
Modulus of elasticity, psi	18 700 000	17 400 000	17 200 000	17 100 000
Rockwell 30T hardness	73.4	75.0	78.4	72.8
Fatigue strength at 10^8 cycles of reversed stress, psi	25 000	26 000	26 000	24 000
Hard Temper				
Tensile strength, psi	97 600	96 100	102 700	93 800
Proportional limit, psi	43 600	46 800	51 800	44 400
Yield strength, psi:				
0.01 per cent offset	63 700	59 400	65 100	55 400
0.2 per cent offset	...	93 900	100 500	90 200
Elongation in 2 in., per cent	2.4	2.6	2.5	3.9
Modulus of elasticity, psi	19 200 000	18 400 000	17 600 000	17 100 000
Rockwell 30T hardness	76.0	77.4	79.3	78.0
Fatigue strength at 10^8 cycles of reversed stress, psi	20 800	27 000	28 000	28 000
Extra-Hard Temper				
Tensile strength, psi	105 300	110 000	103 400	106 400
Proportional limit, psi	46 400	45 300	47 800	44 300
Yield strength, psi:				
0.01 per cent offset	59 700	60 100	57 700	59 600
0.2 per cent offset	102 000	104 400	100 400	108 500
Elongation in 2 in., per cent	1.7	2.2	2.0	2.0
Modulus of elasticity, psi	20 500 000	17 100 000	17 500 000	16 500 000
Rockwell 30T hardness	78.3	80.6	80.3	80.1
Fatigue strength at 10^8 cycles of reversed stress, psi	23 400	24 800	32 000	...

TABLE VI.—*Concluded.*

	18 per cent Nickel Alloy	Standard 12 per cent Nickel Alloy	High Copper 12 per cent Nickel Alloy	High Copper 10 per cent Nickel Alloy
SPRING TEMPER				
Tensile strength, psi	112 300	116 000	113 300	113 300
Proportional limit, psi	48 600	48 900	47 300	43 400
Yield strength, psi:				
0.01 per cent offset	68 000	65 700	58 800	57 600
0.2 per cent offset	...	111 800	107 000	106 500
Elongation in 2 in., per cent	1.6	1.8	1.5	1.5
Modulus of elasticity, psi	20 500 000	17 500 000	16 700 000	16 200 000
Rockwell 30T hardness	79.2	81.9	81.7	81.1
Fatigue strength at 10^8 cycles of reversed stress, psi	24 700	31 000	...	...
EXTRA-SPRING TEMPER				
Tensile strength, psi	115 500	...	...	...
Proportional limit, psi	48 900	...	...	...
Yield strength, psi:				
0.01 per cent offset	...	...	...	...
0.2 per cent offset	...	...	...	...
Elongation in 2 in., per cent	1.7	...	...	...
Modulus of elasticity, psi	...	...	...	...
Rockwell 30T hardness	79.8	...	...	...
Fatigue strength at 10^8 cycles of reversed stress, psi	23 250	...	...	...

per cent offset—show no distinct trend. In general, the highest values were observed in the tests made on longitudinal specimens. Since the values differ by as much as 30 per cent, it is evident that additional data are required.

The per cent elongation in 2 in. is generally the lowest for tests made on longitudinal specimens and highest for specimens blanked at 45 deg to the direction of rolling.

It is customary to assume that the elastic modulus of a given material is constant. This assumption may lead to serious difficulties in engineering designs involving deflection rates for small flat springs. As may be seen from the data given in Tables II to V and in Fig. 3, the modulus of elasticity is not constant. At 45 deg, the values are as much as 14 per cent lower than those reported for longitudinal specimens, while for transverse specimens the values are generally higher, in some cases by as much as 10 per cent.

The results of a more detailed study of the effect of grain direction on the modulus of elasticity for extra-hard temper 18 and 12 per cent nickel silver strip ranging in thickness from 0.010 to 0.032 in. are given in Fig. 12. This shows a drop of approximately 10 per cent at 45 deg and an increase of about 5 per cent for the transverse tests. Since these values will vary slightly for other tempers and thicknesses, additional data are required. Furthermore, it should not be assumed that all non-ferrous materials will show a similar relationship between modulus of elasticity and the rolling or grain direction. For example, typical curves for spring temper type A copper silicon alloy strip and for spring temper 5 per cent tin phosphor bronze strip (Fig. 12) do not show the dip at 45 deg which characterizes the nickel silver alloys. It would therefore appear necessary to establish this relationship for the various alloys for use in critical designs.

Too few data are available to permit any general conclusions as to the effect of grain direction on fatigue strength. The data which are available indicate slightly higher fatigue strengths for transverse specimens than for longitudinal specimens.

From the data available it would appear that grain direction markedly effects the mechanical properties of nickel silver alloys. Adequate data for engineering use are lacking and further work is indicated for design applications.

Studies of the tabulated data, and particularly the average data presented in Fig. 3 and Table VI, indicate that the standard 12 per cent alloy has mechanical properties comparable to those of the 18 per cent alloy. Hence, this material can be substituted in lieu of the 18 per cent nickel silver alloy for spring applications. The only significant difference between the two alloys disclosed by these tests is the slightly lower modulus of elasticity of the 12 per cent alloy. This means that where the rate of build-up is critical it may be necessary to use slightly heavier stock in the 12 per cent alloy to obtain comparable load-deflection characteristics. The data further indicate that the increase in copper content to a nominal value of 60 per cent has no deleterious effect on the mechanical properties of the 12 per cent alloy, whereas decreasing the nickel content to a nominal value of 10 per cent somewhat impairs the elastic properties. While the 10 per cent alloy has fatigue characteristics comparable to those of the 12 and 18 per cent alloys, its lower elastic properties preclude its use in spring applications.

Acknowledgment:

The authors wish to acknowledge the valuable assistance of J. W. Nalencz and R. E. Kudlick who made the tension tests, J. P. Ahrens who assisted in carrying out the bending fatigue studies, and Miss A. V. Jastram who prepared the various charts. Material for these studies was supplied, for the most part, by the Western Electric Co.

REFERENCES

(1) J. R. Townsend, W. A. Straw, and C. H. Davis, "Physical Properties and Methods of Test for Some Sheet Non-Ferrous Metals," *Proceedings*, Am. Soc. Testing Mats., Vol. 29, Part II, p. 381 (1929).

(2) C. H. Greenall and G. R. Gohn, "Fatigue Properties of Non-Ferrous Sheet Metals," *Proceedings*, Am. Soc. Testing Mats., Vol. 37, Part II, p. 160 (1937).

(3) G. R. Gohn and S. M. Arnold, "Stress-Corrosion Properties of Some Non-Ferrous Sheet Metals," Symposium on Stress-Corrosion Cracking of Metals, Am. Soc. Testing Mats., p. 155 (1945). (Issued as separate publication *ASTM STP No. 64*.)

(4) G. R. Gohn, "Conservation of Nickel," ASTM BULLETIN, No. 179, Jan., 1952, p. 32.

REPORT OF COMMITTEE B-6
ON
DIE-CAST METALS AND ALLOYS*

Committee B-6 held two meetings during the year: one in Atlantic City, N. J., on July 1, 1953, and one in Washington, D. C., on February 3, 1954.

There was a balance of $2762.56 in the funds of Committee B-6 as of December 11, 1953.

At the present time, the committee consists of 90 members, of whom 44 are classified as producers, 24 as consumers, and 22 as general interest members.

D. H. Kleppinger was appointed Chairman of Subcommittee V and as the replacement for Sam Tour on the Advisory Committee on Corrosion.

A. T. Lillegren was appointed as the committee's representative on Committee E-11 on Quality Control of Materials.

The election of officers for the ensuing term of two years resulted in selection of the following:

Chairman, W. Babington.
Vice-Chairman, A. E. Weiss.
Secretary, G. L. Werley.

RECOMMENDATIONS ACCEPTED BY THE ADMINISTRATIVE COMMITTEE ON STANDARDS

Subsequent to the 1953 Annual Meeting, Committee B-6 presented to the Society through the Administrative Committee on Standards the recommendation that the Standard Specifications for Zinc-Base Alloy Die Castings (B 86 - 52) be revised and reverted to tentative. The revision consisted of a change in the maximum limit for copper in Alloy XXIII in Table I from 0.10 to 0.15 per cent.

This recommendation was accepted by the Standards Committee on September 9, 1953, and the tentative specifications appear in the 1953 Supplement to Book of ASTM Standards, Part 2.

REVISION OF TENTATIVE

The committee recommends revisions in the Tentative Specifications for Aluminum-Base Alloy Die Castings (**B 85 - 52 T**)[1] as follows:

Section 1.—Revise to include 11 instead of the present 10 alloys.

Table I.—Add the following alloy:

	SC114A
Aluminum, per cent	remainder
Copper, per cent	3.0 to 4.5
Iron, max, per cent	1.3
Silicon, per cent	10.5 to 12.0
Manganese, max, per cent	0.5
Magnesium, max, per cent	0.1
Zinc, max, per cent	1.0
Nickel, max, per cent	0.5
Tin, max, per cent	0.3
Other constituents, except aluminum, max (total), per cent	0.5

Appendix.—Delete the appendix and add a note to the effect that the deletion is temporary pending the accumulation of new mechanical property data.

TENTATIVE CONTINUED WITHOUT REVISION

The committee recommends that the Tentative Specifications for Zinc-Base

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13-18, 1954.

[1] 1952 Book of ASTM Standards, Part 2.

Alloys in Ingot Form for Die Castings (B 240 – 52 T) be continued as tentative without revision.

The recommendations appearing in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[2]

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Aluminum-Base Die-Casting Alloys (E. V. Blackmun, chairman) reports that revision of the table in the Appendix of Specification B 85 – 52 T cannot be undertaken at this time due to the lack of sufficient suitable data. A program has been initiated whereby test bars were die cast for all of the aluminum alloys and the desired mechanical property data will soon be available. In the meantime, as indicated above, the committee has recommended that the Appendix in Specification B 85 be temporarily omitted.

In view of the substantial tonnage of an 11 Si, 3.5 Cu aluminum alloy being used for large thin-walled die castings, the committee has recommended the inclusion of this alloy (SC114A) in Specification B 85 – 52 T. The following supporting data were submitted by the Apex Smelting Co. and the American Smelting and Refining Co.:

Data Supplied by Apex Smelting Co.:

The data supplied by both Apex and American Smelting and Refining Co. are for information only and are not intended as typical properties for use in the Appendix to the specification.

ASTM No.	SC84A	SC114A
Apex No.	39	39-11
ALCOA No.	380	384
Iron, per cent	1.10	1.26
Tensile strength, psi	43 100	43 200
Yield strength, psi	23 000	27 000
Elongation, per cent	3.1	2.0
Charpy impact, ft-lb	2.7	2.2
Brinell hardness	83	95
Tensile strength at 400 F, psi	27 800	32 400
Elongation at 400 F, per cent	5.3	2.9
Resistance to hot cracking	2	1
Pressure tightness	2	1
Die filling capacity	2	1
Resistance to corrosion	4	3
Machining	3	4
Polishing	3	4
Electroplating	1	2
Anodizing	3	4
Chemical oxide coating	5	4

(The physical characteristics are rated (1) to (5), (1) being the best and (5) the least desirable alloy.)

Data Supplied by the American Smelting and Refining Co.:

Two different die casters produced the test bars using commercial die-casting practice. Results of these tests are shown in Tables I and II.

Subcommittee II on Zinc-Base Die-Casting Alloys (A. E. Weiss, chairman) reports progress on the establishment of specification limits for tramp elements in zinc die-casting alloys. Only the limit for silicon remains to be set.

The committee has recommended that the Tentative Specifications for Zinc-Base Alloys in Ingot Form for Die Castings (B 240 – 52 T) be continued as tentative without revision.

One provision of specification writing subcommittees is that at least one half of the membership shall be composed of consumer and general interests. This subcommittee is not properly constituted but will be reorganized promptly either by dropping some producer members or by adding more consumer and general interest members.

Subcommittee V on Exposure and Corrosion Tests (D. H. Kleppinger, chairman) reports that the aluminum alloy test bars of SC84A, with varying amounts of zinc additions, have been exposed as planned. The committee is also laying plans to test, later this year, two aluminum alloys which will then have been exposed for 10 yr in New York City and three aluminum alloys from both Altoona and New York after 20 yr of exposure.

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[2] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

Subcommittee VIII on Brass Die-Casting Alloys (J. C. Fox, chairman) reports that test bars are being prepared by Doehler-Jarvis and the Titan Metals Manufacturing Co. to determine the effects of 0.05 to 0.75 per cent iron in brass alloy ZS331A with the aim of raising the iron limit in this alloy if it can be done without any deleterious effects.

TABLE I.—CHEMICAL COMPOSITION.

Producer	Chemical Composition, per cent						
	Copper	Silicon	Magnesium	Zinc	Iron	Manganese	Nickel
A	3.55	10.70	Nil	0.35	See below	0.31	0.23
B	3.45	10.43	0.01	0.43	0.78	0.48	0.01

TABLE II.—PHYSICAL PROPERTIES.

Pouring Temperature, deg Fahr	Iron, per cent	Number of Bars	Tensile Strength, psi	Yield Strength, psi	Elongation, per cent	Hardness
Producer A:						
1100	0.80	6	(low) 42 300 (high) 46 500 (avg.) 44 600	26 100 27 600 26 800	1.0+ 1.5 1.5	Rockwell B 65
1150	0.93		44 400 46 500 45 000	26 500 27 800 26 900	1.5 2.0 1.5	Rockwell B 66
1200	1.10	7	43 800 47 300 45 500	25 700 26 700 26 400	1.5 2.0 1.5	Rockwell B 65
1250	1.50	6	45 300 49 600 47 800	25 500 27 100 26 200	1.5 2.0 1.5	Rockwell B 65
1300	1.14	6	46 500 48 600 47 300	24 600 25 900 25 200	2.0 3.0 2.0+	Rockwell B 63
Producer B:						
1200	0.78	34—Tensile 17—Yield 17—Elongation 97	37 000 47 000 42 600 Charpy Impact, ft-lb 2.5	20 000 24 800 22 000	2.0 2.5 2.0+	Rockwell B 59 BHN 80

Subcommittee IX on Die-Casting Processes (A. E. Martin, chairman) reports that the Dollin Corp. donated the ASTM test casting die to the committee.

A paper entitled "An Analytical Study of the Die-Casting Process" by Bruno Sachs, a member of this subcommittee, was published in the September, 1953, issue of the ASTM BULLETIN.[3]

This report has been submitted to letter ballot of the committee, which consists of 90 members; 82 members returned their ballots, of whom 80 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

W. BABINGTON,
Chairman.

G. L. WERLEY,
Secretary.

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[3] ASTM BULLETIN, No. 192, September, 1953, p. 27 (TP 117).

REPORT OF COMMITTEE B-7

ON

LIGHT METALS AND ALLOYS, CAST AND WROUGHT*

Committee B-7 on Light Metals and Alloys held two meetings during the year: one at Atlantic City, N. J., in June, 1953, and one in Washington, D. C., in February, 1954.

The committee consists of 89 members, of whom 86 are voting members; 45 are classified as producers, 30 as consumers, and 14 as general interest members.

F. M. Howell was appointed Committee B-7 representative on the Committee E-1 Task Group on Bend Testing.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, I. V. Williams.
Vice-Chairman, C. B. Gleason.
Secretary, R. B. Smith.

REVISION OF TENTATIVES

The committee recommends that the following 13 tentatives be revised as set forth in the Appendix of this report:[1]

Tentative Specifications for:

Aluminum-Base Alloy Sand Castings (**B 26 - 52 T**),[2]
Magnesium-Base Alloy Forgings (**B 91 - 49 T**),[2]
Aluminum-Base Alloy Permanent Mold Castings (**B 108 - 52 T**),[2]
Aluminum and Aluminum-Alloy Sheet and Plate for Pressure Vessel Applications (**B 178 - 53 T**),[3]
Aluminum and Aluminum-Alloy Sheet and Plate (**B 209 - 53 T**),[3]
Aluminum-Alloy Drawn Seamless Tubes (**B 210 - 53 T**),[3]
Aluminum and Aluminum-Alloy Bars, Rods, and Wire (**B 211 - 53 T**),[3]
Aluminum and Aluminum-Alloy Extruded Bars, Rods, and Shapes (**B 221 - 53 T**),[3]
Aluminum-Alloy Extruded Tubes (**B 235 - 53 T**),[3]
Aluminum-Alloy Pipe (**B 241 - 53 T**),[3]
Aluminum-Alloy Die Forgings (**B 247 - 50 T**),[2]
Aluminum and Aluminum-Alloy Bars, Rods, and Shapes for Pressure Vessel Applications (**B 273 - 53 T**),[3] and
Aluminum and Aluminum-Alloy Pipe and Tube for Pressure Vessel Applications (**B 274 - 53 T**).[3]

TENTATIVES CONTINUED WITHOUT REVISION

The committee recommends that the following four tentative specifications, which have stood for two years or more without revision, be continued as tentative because it is anticipated that new alloys will be added to the specifications or changes made in the requirements:

Tentative Specifications for:

Magnesium-Base Alloy Sheet (B 90 - 51 T),
Magnesium-Base Alloys in Ingot Form for Sand Castings, Die Castings, and Permanent Mold Castings (B 93 - 52 T),
Magnesium-Base Alloy Permanent Mold Castings (B 199 - 51 T),[3a] and
Aluminum Bars for Electrical Purposes (Bus Bars) (B 236 - 52 T).

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[4]

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Aluminum and Aluminum Alloy Ingots (R. A. Quadt, chairman) is preparing a revision of the

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13-18, 1954.

[1] See p. 263.

[2] 1952 Book of ASTM Standards, Part 2.

[3] 1953 Supplement to Book of ASTM Standards, Part 2.

[3a] See Editorial Note, p. 262.

[4] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

Tentative Specifications for Aluminum-Base Alloys in Ingot Form for Sand Castings, Die Castings, and Permanent Mold Castings (**B 179 – 53**).

Subcommittee II on Aluminum Alloy Castings (D. L. Colwell, chairman) prepared revisions of the Tentative Specifications for Aluminum-Base Alloy Sand Castings (**B 26 – 52 T**)[3a] and Aluminum-Base Alloy Permanent Mold Castings (**B 108 – 52 T**),[3a] as set forth in the Appendix I to this report, to add minimum yield strength requirements for use when required for such applications as pressure vessels.

Subcommittee III on Wrought Aluminum and Wrought Aluminum Alloys (P. V. Faragher, chairman) prepared revisions of ten of the Tentative Specifications, set forth in the Appendix to this report, to bring them into agreement with industry standards, and is progressing on revision of the Tentative Specifications for Aluminum Bars for Electrical Purposes (Bus Bars) (**B 236 – 52 T**).

Subcommittee IV on Magnesium and Magnesium Alloys, Cast and Wrought (A. A. Moore, chairman) prepared a revision of the Tentative Specifications for Magnesium-Base Alloy Forgings (**B 91 – 49 T**), as set forth in the Appendix to this report, to add alloy ZK60A, and is progressing on revision of the Tentative Specifications for Magnesium-Base Alloy Sand Castings (**B 80 – 53 T**)[3a] and Magnesium-Base Alloy Permanent Mold Castings (**B 199 – 51 T**)[3a] to add a tabulation of the properties and characteristics of magnesium casting alloys.

Subcommittee V on Testing Light Metals (R. L. Templin, chairman) has sought the assistance of Committee E-11 on Quality Control of Materials in establishing lot sizes to be used in defining a statistically satisfactory sampling method for the frequency of mechanical testing requirements.

Subcommittee VI on Anodic Oxidation of Aluminum and Magnesium Alloys (Fred Keller, chairman) is progressing on development of specifications for anodic coatings for various applications and of engineering data on the characteristics affecting the performance of anodic coatings on the various aluminum alloys and products.

Subcommittee VII on Codification of Light Metals and Alloys, Cast and Wrought (R. B. Smith, chairman) has prepared two proposed Tentative Recommended Practices for Temper Designations of Light Metals and Alloys, Cast and Wrought, and is attempting to determine which should be recommended for publication.

Subcommittee VIII on Atmospheric Exposure Tests (L. H. Adam, chairman) has test specimens of 27 aluminum and 10 magnesium alloys installed at four of the five Society atmospheric exposure test sites: for two years on top of the Port of Authority Building, New York City, for industrial atmospheric conditions; two years at State College, Pa., for rural atmospheric conditions; one and a half years at Kure Beach, N. C., for Atlantic Coast marine, and one year at Point Reyes, Calif., for Pacific Coast marine atmospheric conditions. It is expected that installation of specimens will be completed by June, 1954, at the Freeport, Tex., Gulf Coast marine site. A paper on "Atmospheric Exposure of Aluminum and Magnesium Sand and Permanent Mold Castings" represented by these specimens is appended to this report.[5]

This report has been submitted to a letter ballot of the committee, which consists of 90 members; 59½ members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

I. V. Williams,
Chairman.

R. B. Smith,
Secretary.

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[5] See p. 270.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee B-7 presented to the Society through the Administrative Committee on Standards the following recommendations:

Tentative Recommended Practice for:
Temper Designation of Light Metals and Alloys, Cast and Wrought (B 296 - 54 T).

Revision of Tentative Specifications for:

Aluminum-Base Alloy Sand Castings (B 26 - 54 T),
Magnesium-Base Alloy Sand Castings (B 80 - 53 T),
Aluminum-Base Alloy Permanent Mold Castings (B 108 - 54 T),
Aluminum and Aluminum-Alloy Sheet and Plate for Pressure Vessel Applications (B 178 - 54 T),
Aluminum and Aluminum-Alloy Sheet and Plate (B 209 - 54 T),
Magnesium-Base Alloy Permanent Mold Castings (B 199 - 51 T),
Aluminum and Aluminum-Alloy Extruded Bars, Rods, and Shapes (B 221 - 54 T), and
Aluminum-Alloy Drawn Seamless Tubes for Condensers and Heat Exchangers (B 234 - 53 T).

The revisions of Specifications B 26 and B 108 were accepted by the Standards Committee on November 5, 1954, and the remaining recommendations were accepted on September 28, 1954; all appear in the 1954 Supplement to Book of ASTM Standards, Part 2.

APPENDIX I

RECOMMENDATIONS AFFECTING STANDARDS FOR LIGHT METALS AND ALLOYS, CAST AND WROUGHT

In this Appendix are given the recommendations affecting certain standards covering light metals and alloys which are referred to earlier in this report. The standards appear in their present form in the 1952 Book of ASTM Standards, Part 2, or the 1953 Supplement to Book of ASTM Standards, Part 2.

TABLE I.—TENSILE REQUIREMENTS.
(Revisions in Table II of B 26 – 52 T)

Alloy	Condition	Yield Strength, (0.2 per cent offset), min, psi
C4A	T4 (solution heat treated)	13 000
	T6 (solution treated and aged)	20 000
	T62 (solution treated and aged)	28 000
	T7 (solution treated and over-aged)	16 000
CG100A	T2 (annealed)	......
	T61 (solution treated and aged)	......
CN42A	T21 (annealed)	......
	T61 (solution treated and aged)	20 000
CS43A	F (as cast)	12 000
CS72A	F (as cast)	12 000
G4A	F (as cast)	9 000
G10A	T4 (solution heat treated)	22 000
GS42A	F (as cast)	10 000
S5A	F (as cast)	6 000
S5B	F (as cast)	7 000
SC51A	T6 (solution treated and aged)	20 000
	T51 (aged)	18 000
	T71 (solution treated and over-aged)	22 000
SC64B	F (as cast)	12 000
	T6 (solution treated and aged)	20 000
SC64C	F (as cast)	14 000
	T6 (solution treated and aged)	20 000
SC82A	F (as cast)	14 000
	T6 (solution treated and aged)	21 000
SG70A	T6 (solution treated and aged)	20 000
	T51 (aged)	16 000

REVISIONS OF TENTATIVE SPECIFICATIONS

The committee recommends that the following 13 tentative specifications be revised as indicated below and continued as tentative.

TABLE II.—TENSILE REQUIREMENTS.
(Revisions in Table II of B 91 - 49 T)

Alloy	Tensile Strength, min, psi	Yield Strength (0.2 per cent offset), min, psi	Elongation in 2 in., min, per cent
ZK60A-T5—Die forgings	42 000[b]	26 000[b]	7.0[b]
ZK60A-T5—Hand forgings	38 000[c]	20 000[c]	7.0[c]

[b] Applicable for forgings not more than 3 in. in thickness.

[c] Applicable for forgings not more than 6 in. in thickness.

Specifications for Aluminum-Base Alloy Sand Castings (B 26 - 52 T):[1,1a]

Section 6(a).—Revise to read as follows:

6. (*a*) The tension test specimens representing the castings shall conform to the requirements as to tensile properties prescribed in Table II. Yield strength tests are included for highly stressed applications such as pressure vessels, and need not be made unless specifically indicated in the contract or purchase order. It is desirable to avoid yield strength determinations whenever possible on alloys of less than 1 per cent minimum required elongation because of possible damage to the extensometer.

Table II.—Revise by the addition of minimum yield strength requirements for the alloys shown in the accompanying Table I.

Table IV.—Delete, since typical yield strengths are replaced with minimum yield strength requirements in Table II.

Table V.—Renumber as Table IV, and revise the approximate melting range for alloy ZG32A from "1030 to 1175" to "1105 to 1180" F, and for alloy ZG42A from "1020 to 1170" to "1085 to 1165" F.

Specifications for Magnesium-Base Alloy Forgings (B 91 - 49 T):[1]

Table I.—Add requirements for alloy ZK60A as follows:

Magnesium, per cent	remainder
Zinc, per cent	4.8 to 6.2
Zirconium, min, per cent	0.45
Other impurities, max, per cent	0.3

TABLE III.
(Revisions in Table III of B 91 - 49 T)

Alloy	Yield Strength (0.2 per cent offset), min, psi	Unit Deformation, inch per inch of gage length
ZK60A-T5—Die forgings	26 000	0.0060
ZK60A-T5—Hand forgings	20 000	0.0051

Table II.—Add requirements for alloy ZK60A-T5 as shown in accompanying Table II.

Table III.—Add requirements for alloy ZK60A-T5 as shown in accompanying Table III.

Explanatory Note 2.—Add the following:

Alloy ZK60A.—This alloy has a specific gravity of about 1.83. It has excellent press forging characteristics and the best combination of strength and ductility of the magnesium forging alloys.

Specifications for Aluminum-Base Alloy Permanent Mold Castings (B 108 - 52 T):[1,1a]

Section 6(a).—Revise to read as shown in Section 6(*a*) of Specifications B 26 above.

Table II.—Revise by the addition of the minimum yield strength requirements for the alloys shown in the accompanying Table IV. Add the alloy GS42A . . . F (as cast) with requirements for Tensile Strength, min, of 19,000 psi; and for Elongation in 2 in., min, of 1.5 per cent.

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[1] 1952 Book of ASTM Standards, Part 2.

[1a] See Editorial Note, p. 262.

Table IV.—Delete, since typical yield strengths are replaced with minimum yield strength requirements in Table II.

Table V.—Renumber as Table IV and revise the approximate melting range for alloy ZG32A from "1030 to 1175" to "1105 to 1180" F, and for ZG42A from "1020 to 1170" to "1085 to 1165" F.

TABLE IV.—TENSILE REQUIREMENTS.

(Revisions in Table II of B 108 - 52 T)

Alloy	Condition	Yield Strength (0.2 per cent offset), min, psi
CG100A	T551 (aged)	......
	T65 (solution treated and aged)	......
CN42A	T571 (aged)	......
	T61 (solution treated and aged)	......
CS42A	T4 (solution heat treated)	15 000
	T6 (solution treated and aged)	22 000
	T7 (solution treated and over-aged)	16 000
CS66A	T5 (aged)	25 000
CS72A	F (as cast)	14 000
CS104A	F (as cast)	[b]
GS42A	F (as cast)	......
GZ42A	F (as cast)	12 000
S5A	F (as cast)	6 000
S5B	F (as cast)	7 000
SC51A	T6 (solution treated and aged)	23 000
SC64A	F (as cast)	12 000
SC64B	F (as cast)	13 000
	T61 (solution treated and aged)	26 000
SC64C	F (as cast)	15 000
SC122A	T5 (aged)	26 000
	T65 (solution treated and aged)	32 000
SG70A	T6 (solution treated and aged)	22 000
SN122A	T551 (aged)	......
	T65 (solution treated and aged)	......
ZC60A	T5[e]	18 000

[b] Not required.

Specifications for Aluminum and Aluminum-Alloy Sheet and Plate for Pressure Vessel Applications (B 178 - 53 T):[1a,2]

Section 7.—Delete the note, and revise the first sentence to read as follows:

7. Tension test specimens for sheet or plate of alloys 990A, 996A, G1A, GR20A, GR40A, M1A, Clad M1A, MG11A, and Clad MG11A shall be taken parallel to the direction of rolling; for sheet or plate of alloys GS11A and Clad GS11A the tension test specimen shall be taken perpendicular to the direction of rolling for widths 9 in. and greater, and parallel to the direction of rolling for widths less than 9 in.

Table I.—For alloy 990A revise the manganese limit of "0.10" to "0.05" per cent. For alloy G1A revise the copper limit of "0.25" to "0.20," the iron limit from "0.8" to "0.7," the silicon limit from "0.50" to "0.40," and the manganese limit from "0.15" to "0.10" per cent. For alloy GS11A and the core

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[2] 1953 Supplement to Book of ASTM Standards, Part 2.

of Clad GS11A revise the zinc limit from "0.20" to "0.25" per cent.

Table II.—For alloy GR40A-O add a maximum tensile strength requirement of 41,000 psi in addition to the minimum requirement of 30,000 psi now specified.

TABLE V.—TENSILE REQUIREMENTS.
(Revisions in Table II of B 210 - 53 T)

Alloy	Temper	Wall Thickness, in.	Tensile Strength, psi		Yield Strength, psi		Elongation in 2 in. or 4 × Diameter, min, per cent	
			Min	Max	Min	Max	Full-Section Specimens	Cut-Out Specimens
GS11C....	O.........	0.010 to 0.500	...	22 000	...	14 000	...	...
	T4......	0.025 to 0.049	30 000	...	16 000	...	16	14
		0.050 to 0.259	30 000	...	16 000	...	18	16
		0.260 to 0.500	30 000	...	16 000	...	20	18
	T6......	0.025 to 0.049	42 000	...	35 000	...	10	8
		0.050 to 0.259	42 000	...	35 000	...	12	10
		0.260 to 0.500	42 000	...	35 000	...	14	12

TABLE VI.—TENSILE REQUIREMENTS.
(Revisions in Table II of B 221 - 53 T)

Alloy	Temper	Thickness, in.	Tensile Strength, psi		Yield Strength, psi		Elongation in 4 × Diameter, min, per cent
			Min	Max	Min	Max	
GS10A.......	T6.....	Up to 0.124	32 000	...	25 000	...	8.0
		0.125 to 0.500	32 000	...	25 000	...	10.0
GS11C.....	O........	all sizes	...	22 000	...	16 000	16.0
	T4.......	all sizes	26 000	...	16 000	...	16.0
	T6.......	all sizes	38 000	...	35 000	...	10.0

Specifications for Aluminum and Aluminum-Alloy Sheet and Plate (B 209 - 53 T):[1a,2]

Section 8(a).—Delete the note, and revise the first sentence to read as follows:

> 8. (*a*) Tension test specimens for sheet or plate of alloys 990A, G1A, GR20A, M1A, and MG11A shall be taken parallel to the direction of rolling; for sheet or plate of alloys CG42A, Clad CG42A, Clad CS41A, GS11A, ZG62A, and Clad ZG62A the tension test specimen shall be taken perpendicular to the direction of rolling for widths 9 in. and greater, and parallel to the direction of rolling for widths less than 9 in.

Table I.—For alloy 990A revise the manganese limit from "0.10" to "0.05" per cent. For alloy CG42A and the core of Clad CG42A revise the zinc limit from "0.10" to "0.25" per cent and the chromium limit from "0.25" to "0.10" per cent. For the core of Clad CS41A alloy revise the chromium limit from "0.25" to "0.10" per cent. For alloy G1A revise the copper limit from "0.25" to "0.20," the iron limit from "0.8" to "0.7," the silicon limit from "0.50" to "0.40," and the manganese limit from "0.15" to "0.10" per cent. For alloy GS11A revise the zinc limit from "0.20" to "0.25" per cent.

Specifications for Aluminum-Alloy Drawn Seamless Tubes (B 210 – 53 T):[2]

Table I.—For alloy CG42A revise the zinc limit from "0.10" to "0.25" per cent and the chromium limit from "0.25" to "0.10" per cent. For alloy G1A revise the copper limit from "0.25" to "0.20," the iron limit from "0.8" to "0.7," the silicon limit from "0.50" to "0.40," and the manganese limit from "0.15" to "0.10" per cent. For alloy GS11A revise the zinc limit from "0.20" to "0.25" per cent. Add requirements for alloy GS11C as follows:

Aluminum, per cent	remainder
Copper, per cent	0.15 to 0.40
Iron, per cent	0.7
Silicon, per cent	0.40 to 0.8
Manganese, per cent	0.15
Magnesium, per cent	0.8 to 1.2
Zinc, per cent	0.25
Chromium, per cent	0.04 to 0.14
Titanium, per cent	0.15
Other elements, each, per cent	0.05
Other elements, total, per cent	0.15

Table II.—Add requirements for alloy GS11C as shown in the accompanying Table V.

Table III.—Revise the headings of the second and fourth columns to add alloy GS11C.

Table IV.—Revise the headings of the second and fourth columns to add alloy GS11C.

Specifications for Aluminum and Aluminum-Alloy Bars, Rods, and Wire (B 211 – 53 T):[2]

Table I.—For alloy 990A revise the manganese limit from "0.10" to "0.05" per cent. For alloys CG42A and CM41A revise the zinc limit from "0.10" to "0.25" per cent and the chromium limit from "0.25" to "0.10" per cent. For alloy CB60A revise the limit for other elements, total, from "0.20" to "0.15" per cent. For alloy GS11A revise the zinc limit from "0.20" to "0.25" per cent. Delete alloy CM41B and all requirements pertaining to it. In Footnote *c* delete CM41.

Table II.—Delete alloy CM41B and all requirements pertaining to it.

Specifications for Aluminum and Aluminum-Alloy Extruded Bars, Rods, and Shapes (B 221 – 53 T):[1a,2]

Table I.—For alloy 990A revise the manganese limit from "0.10" to "0.05" per cent. For alloy CG42A revise the zinc limit from "0.10" to "0.25" per cent and the chromium limit from "0.25" to "0.10" per cent. For alloy GS10A revise the iron limit from "0.50" to "0.35" per cent and the magnesium range from "0.45 to 0.85" to "0.45 to 0.9" per cent. For alloy GS11A revise the zinc limit from "0.20" to "0.25" per cent. For alloy GS11B delete the titanium limit of "0.15" per cent. Add requirements for alloy GS11C as given for Table I of Specifications B210 above.

Table II.—Add requirements for alloy GS10A-T6 and alloy GS11C as shown in the accompanying Table VI.

Specifications for Aluminum-Alloy Extruded Tubes (B 235 – 53 T):[2]

Table I.—For alloy CG42A revise the zinc limit from "0.10" to "0.25" per cent. For alloy GS10A revise the iron limit from "0.50" to "0.35" per cent. For alloy GS11A revise the zinc limit from "0.20" to "0.25" per cent. Add requirements for alloy GS11C as given for Table I of Specifications B210 above.

Table II.—Add requirements for alloy GS11C as shown in the accompanying Table VII.

Specifications for Aluminum-Alloy Pipe (B 241 – 53 T):[2]

Section 12(b).—Revise the third line to change temper F to temper H112.

Table I.—For alloy GS10A revise the iron limit from "0.50" to "0.35" per cent and the magnesium range from "0.45 to 0.85" to "0.45 to 0.9" per cent. For alloy

GS11A revise the zinc limit from “0.20” to “0.25” per cent. Add requirements for alloy GS11C as given for Table I of Specifications B210 above.

Table II.—For alloy M1A change temper F to temper H112. Add requirements for alloy GS11C as shown in the accompanying Table VIII.

Table III.—Revise the headings of columns 4 and 7 to add alloy GS11C.

TABLE VII.—TENSILE REQUIREMENTS.
(Revisions in Table II of B 235 – 53 T)

Alloy	Temper	Wall Thickness, in.	Tensile Strength, psi		Yield Strength, psi		Elongation in 2 in. or 4 × Diameter, min, per cent
			Min	Max	Min	Max	
GS11C.....	0........	0.050 and over	...	22 000	...	16 000	16
	F........	0.050 and over	[f]		...	...	...
	T4.......	0.050 and over	26 000	...	16 000	...	16
	T6.......	0.050 and over	38 000	...	35 000	...	10
	T62......	0.050 and over	35 000	...	26 000	...	10

[f] Not required.

TABLE VIII.—TENSILE REQUIREMENTS.
(Revisions in Table II of B 241 – 53 T)

Alloy	Temper	Pipe Size, in.	Tensile Strength, min, psi	Yield Strength, min, psi	Elongation in 2 in. or 4 × Diameter, min, per cent
GS11C..........	T6..........	Under 1	42 000	35 000	12
		1 and over	38 000	35 000	10

Specifications for Aluminum-Alloy Die Forgings (B 247 – 50 T):[1]

Table I.—For alloy CN42C revise the silicon limit from “0.90” to “0.9” per cent and the magnesium range from “0.45 to 0.90” to “0.45 to 0.9” per cent. For alloy CN42D revise the silicon limit from “0.90” to “0.9” per cent and delete the titanium limit of “0.05” per cent. For alloy CS41A revise the magnesium range from “0.20 to 0.80” to “0.20 to 0.8” per cent. For alloy GS11A revise the iron limit from “0.70” to “0.7” per cent, the silicon range from “0.40 to 0.80” to “0.40 to 0.8” per cent, the magnesium range from “0.80 to 1.2” to “0.8 to 1.2” per cent, and the zinc limit from “0.20” to “0.25” per cent. For alloy GS11B delete the titanium limit of “0.15” per cent. For alloy M1A revise the iron limit from “0.70” to “0.7” per cent and the silicon limit from “0.60” to “0.6” per cent. For alloy SG11A revise the silicon range from “0.60 to 1.2” to “0.6 to 1.2” per cent and the magnesium range from “0.45 to 0.80” to “0.45 to 0.8” per cent. For SG121A revise the silicon range from “11.5 to 13.5” to “11.0 to 13.5” per cent and the magnesium range from “0.80 to 1.3” to “0.8 to 1.3” per cent. For alloy ZG62A revise the iron limit of “0.70” to “0.7” per cent.

Specifications for Aluminum and Aluminum-Alloy Bars, Rods, and Shapes for Pressure Vessel Applications (B 273 – 53 T):[2]

Table I.—For alloy CG42A revise the zinc limit from “0.10” to “0.25” per cent and the chromium limit from “0.25” to “0.10” per cent. For alloy GS11A revise the zinc limit from “0.20”

to "0.25" per cent. Add requirements for alloy GS11C as given for Table I of Specifications B210 above.

Table II.—Revise requirements for alloys 990A, GR40A, and M1A and add requirements for alloy GS11C as shown in the accompanying Table IX.

TABLE IX.—TENSILE REQUIREMENTS.
(Revisions in Table II of B 273 – 53 T)

Alloy	Temper	Thickness, in.	Tensile Strength, psi		Yield Strength, min, psi	Elongation in 2 in. or 4 × Diameter, min, per cent
			Min	Max		
990A..........	0...............	all sizes	11 000	15 500	3 000	...
	H112..........	all sizes	11 000	...	3 000	...
GR40A.......	0...............	all sizes	30 000	41 000	11 000	...
	H112..........	all sizes	30 000	...	11 000	...
GS11C.......	T4.............	all sizes	26 000	...	16 000	16
	T6.............	all sizes	38 000	...	35 000	10
M1A..........	0...............	all sizes	14 000	19 000	5 000	...
	H112..........	all sizes	14 000	...	5 000	...

TABLE X.—TENSILE REQUIREMENTS.
(Revisions in Table II of B 274 – 53 T)

Alloy	Temper	Pipe Size, in.	Tube Wall Thickness, in.	Tensile Strength, min, psi	Yield Strength, min, psi	Elongation in 2 in. or 4 × Diameter, min, per cent
GS11C........	T4.............	...	0.025 and over	26 000	16 000	14
	T6.............	all	0.025 and over	38 000	35 000	8
	T62...........	...	0.050 and over	35 000	26 000	10

Table III.—Replace with Table III of Specifications B 221.

Table VII.—Revise the title to read: "Permissible Variations in Dimensions of Rolled or Extruded Structural Shapes."

Specifications for Aluminum and Aluminum-Alloy Pipe and Tube for Pressure Vessel Applications (B 274 – 53 T):[2]

Section 1.—Revise the note to add alloy GS11C.

Table I.—For alloy CG42A revise the zinc limit from "0.10" to "0.25" per cent and the chromium limit from "0.25" to "0.10" per cent. For alloy CS41A revise the chromium limit from "0.25" to "0.10" per cent. For alloy G1A revise the copper limit from "0.25" to "0.20," the iron limit from "0.8" to "0.7," the silicon limit from "0.50" to "0.40," and the manganese limit from "0.15" to "0.10" per cent. For alloy GS10A revise the iron limit from "0.50" to "0.35" per cent. For alloy GS11A revise the zinc limit from "0.20" to "0.25" per cent. Add requirements for alloy GS11C as given for Table I of Specifications B 210 above.

Table II.—Add requirements for alloy GS11C as shown in the accompanying Table X.

Table III.—Revise the table in Footnote *a* to add alloy GS11C with a conversion factor of 1.00.

APPENDIX II

ATMOSPHERIC EXPOSURE OF ALUMINUM AND MAGNESIUM SAND AND PERMANENT MOLD CASTINGS

By L. H. Adam[1] and Marie Dougherty[1]

Periodically over the next few years, Committee B-7 on Light Metals and Alloys, Cast and Wrought, will be reporting data collected on the specimens of wrought and cast light metals exposed at the selected sites representing industrial rural, and various seacoast conditions. Details of the scope of the program were presented at the 1953 Annual Meeting.[2]

The present report pertains to only the 14 cast aluminum and 5 magnesium alloys exposed for 1 yr at the industrial site located on top of the Port Authority Building in the center of New York City, the rural site at State College, Pa., and the East Coast site, 800 ft from the ocean, at Kure Beach, N. C. Unfortunately, due to the delays of erecting racks and installations of the specimens, the West Coast site at Point Reyes, Calif., and the Freeport, Tex. site cannot be included. The sand- and permanent-mold-cast aluminum alloys are listed together with their check chemical analysis in Table I. The five magnesium sand-casting alloys are listed in Table II. The ASTM Specification applicable is indicated in each instance.

The various specimens included in the program have been exposed at the sites in the standard racks, as shown in Fig. 1, with plastic insulators retaining the specimens in place. The original plans required specimen removal after 6-months and 1-, 3-, 5-, and 10-yr exposures. Although the specimens exposed at the sites contained various degrees of surface corrosion, as shown in Figs. 2 and 3, for two magnesium alloys, the evaluation of the effects of the exposures was to be based on any changes reflected in the tensile strength. Any additional data were for information only.

The data collected on the representative specimens are given in Table III to Table XXVIII inclusive. A brief summary of these data is shown in Figs. 4, 5, 6.

Seven noticeable observations of significance are:

Aluminum

C4A-T6 Sand Casting	At least a 5 per cent decline in tensile strength in specimens after exposure for 6 months at Kure Beach with no significant change after the 1-yr period.
G10A-T4 Sand Casting	The specific specimens under test have ductility values considerably lower than the requirement of

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[1] Materials Engineer and Physical Science Aide, respectively, Frankford Arsenal, Pitman Dunn Laboratories, Philadelphia, Pa.

[2] Appendix to Report of Committee B-7 on Light Metals and Alloys, Cast and Wrought, *Proceedings*, Am. Soc. Testing Mats., Vol. 53, pp. 227–250 (1953).

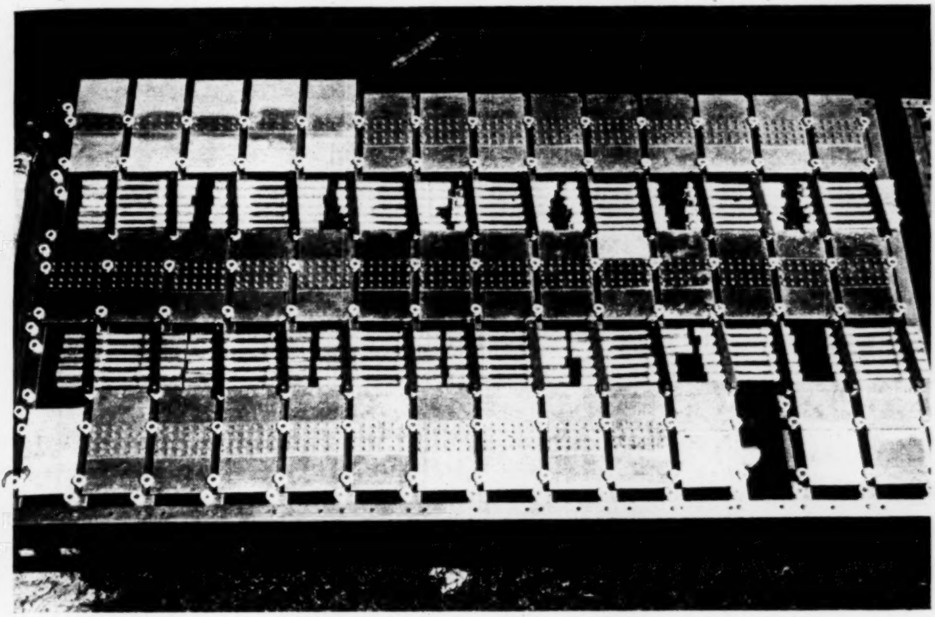


FIG. 1.—Atmospheric Exposure Racks Located at the Gulf Coast—Brazos River Test Site, Freeport, Tex., Showing Arrangement of Exposure Tests on Aluminum and Magnesium Alloys.

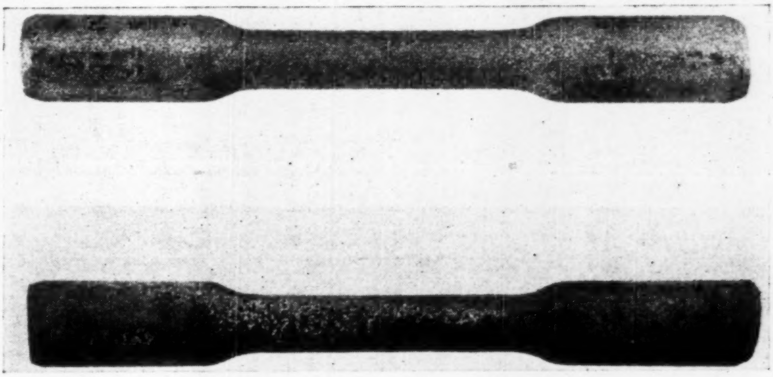


FIG. 2.—Photograph Showing Sand-Cast Tension Specimens—AZ91C-T6, After 6-months Exposure.

Upper casting reveals effects of rural atmosphere, while lower casting represents marine atmospheric effects along the Atlantic Coast.

TABLE I.—CHEMICAL ANALYSES OF ALUMINUM ALLOY CASTINGS USED IN THE 10-YR ATMOSPHERIC EXPOSURE PROGRAM SPONSORED BY THE ASTM COMMITTEE B-7.

Aluminum Alloys Designations			Chemical Composition, per cent											
Commercial	ASTM		Aluminum	Copper	Iron	Silicon	Manganese	Magnesium	Zinc	Chromium	Titanium	Nickel	Others	
													Each	Total
43	S5B	ASTM Spec[c, d]	Remainder	0.6	0.8	4.5 to 6.0	0.3	0.05	0.3	0.2	0.2			0.3
	Sand casting	As Rec'd Values	Remainder	0.44	0.56	5.86	0.3	0.02	0.03	0.05	0.07			
	Permanent mold	As Rec'd Values	Remainder	0.44	0.50	5.84	0.3	0.03	0.04	0.07	0.04			
195	C4A	ASTM Spec[c]	Remainder	4.0 to 5.0	1.0	1.5	0.3	0.03	0.3		0.2		0.05	0.15
	Sand casting	As Rec'd Values	Remainder	4.59	0.38	0.53	0.11	<0.01	<0.03		0.15			
220	G10A Sand casting	ASTM Spec[c]	Remainder	0.2	0.3	0.2	0.1	9.5 to 10.6	0.1		0.2			
		As Rec'd Values	Remainder	0.09	0.12	0.06	<0.01	10.6	<0.03		<0.01			
355	SC51A	ASTM Spec[c, d]	Remainder	1.0 to 1.5	0.8[a]	4.5 to 5.5	0.5[a]	0.4 to 0.6	0.3	0.2	0.2		0.05	0.15
	Sand casting	As Rec'd Values	Remainder	1.37	0.42	5.7[b]	0.24	0.48	0.17	0.06	0.05	0.08		
	Permanent mold	As Rec'd Values	Remainder	1.40	0.45	5.5	0.27	0.59	0.17	0.08	0.06	0.08		
356	SG70A	ASTM Spec[c]	Remainder	0.2	0.6	6.5 to 7.5	0.3	0.2 to 0.4	0.3		0.2		0.05	0.15
	Sand casting	As Rec'd Values	Remainder	0.03	0.22	7.10	<0.01	0.24	<0.01		0.14			
All Cast	SC64B	ASTM Spec[c, d]	Remainder	3.3 to 4.3	1.0	5.5 to 7.0	0.5	0.1	1.0		0.2	0.3		0.5
	Sand casting	As Rec'd Values	Remainder	3.99	0.45	5.99	0.32	0.1	0.8		0.06	0.3		
	Permanent mold	As Rec'd Values	Remainder	3.59	0.52	6.05	0.43	0.1	0.73		0.07	0.3		
40E	ZG61A	ASTM Spec[c]	Remainder	0.3	1.0	0.25	0.3	0.5 to 0.65	5.2 to 6.0	0.4 to 0.6	0.1 to 0.25		0.05	0.2
	Sand casting	As Rec'd Values	Remainder	0.10	0.25	0.14	0.03	0.63	5.76	0.45	0.24			
108	CS43A	ASTM Spec[c]	Remainder	3.5 to 4.5	1.2	2.5 to 3.5	0.5	0.05	1.0		0.2	0.3		0.5
	Sand casting	As Rec'd Values	Remainder	4.08	1.01	3.37	0.48	0.01	0.51		<0.05	0.3		

Ternalloy 5	ZG32A	ASTM Spec$^{c,\,d}$	Remainder	0.2	0.8	0.2	0.4 to 0.6	1.4 to 1.8	2.7 to 3.3	0.2 to 0.4			0.05	
	Sand casting	As Rec'd Values	Remainder	0.02	0.16	<0.10	0.57	1.8	3.10	0.27	0.05			
	Permanent mold	As Rec'd Values	Remainder	<0.01	0.25	0.05	0.48	1.7	3.13	0.25	0.16			
Ternalloy 7	ZG42A	ASTM Spec$^{c,\,d}$	Remainder	0.2	0.8	0.2	0.4 to 0.6	1.8 to 2.4	4.0 to 4.5	0.2 to 0.4	0.2		0.05	
	Sand casting	As Rec'd Values	Remainder	0.06	0.24	<0.10	0.58	2.15	4.4	0.23	0.20			
	Permanent mold	As Rec'd Values	Remainder	0.09	0.19	0.19	0.51	2.28	4.5	0.24	0.15			
A612	ZG61B	ASTM Spec^{c}	Remainder	0.35 to 0.65	0.5	0.15	0.05	0.6 to 0.8	6.0 to 7.0		0.2		0.05	0.15
	Sand casting	As Rec'd Values	Remainder	0.51	0.30	0.13	<0.01	0.71	6.58		0.14			
C612	ZG60A	ASTM Spec^{d}	Remainder	0.35 to 0.65	1.4	0.3	0.05	0.25 to 0.45	6.0 to 7.0		0.2		0.05	0.15
	Permanent mold	As Rec'd Values	Remainder	0.42	0.89	<0.10	<0.01	0.25	6.60		0.16			
Tensiloy	ZC81B	ASTM Spec^{d}	Remainder	0.4 to 1.0	1.3	0.3	0.6	0.2 to 0.5	7.0 to 8.0	0.3	0.2	0.1	0.1	0.2
	Permanent mold	As Rec'd Values	Remainder	0.89	1.3	0.12	0.37	0.23	7.09	0.09	0.15			
Tensiloy	ZC81A	ASTM Spec^{c}	Remainder	0.4 to 1.0	1.0	0.3	0.6	0.2 to 0.5	7.0 to 8.0	0.3	0.2	0.1	0.1	0.2
	Sand casting	As Rec'd Values	Remainder	0.62	0.27	0.08	0.08	0.40	7.65	0.11	0.12	0.02		

[a] If the iron content exceeds 0.4 per cent, it is desirable to have Mn present in an amount equal to one half of the iron.

[b] High.

[c] Tentative Specifications for Aluminum-Base Alloy Sand Castings (B 26 – 52 T), 1952 Book of ASTM Standards, Part 2, p. 522.

[d] Tentative Specifications for Aluminum-Base Alloy Permanent Mold Castings (B 108 – 52 T), 1952 Book of ASTM Standards, Part 2, p. 551.

NOTE 1.—When single units are shown in ASTM Specifications, these indicate the maximum amount permitted.

	ASTM Specification B 26. Further decline in ductility is noted in the specimen after 1-yr exposure at Kure Beach.
SC51A-T6 Permanent Mold	At least 4 per cent decline in tensile strength after 1-yr exposure at Kure Beach.
ZG32A-T5 Permanent Mold	A marked decrease in ductility after 1-yr exposure at Kure Beach with little change in tensile strength.
ZG81B-T5 Permanent Mold	At least 10 per cent decline in tensile strength in specimens exposed 6 months at Kure Beach. Rural or industrial exposed specimens did not indicate any significant change.
Magnesium	
EZ30-F	At least a 5 per cent decline in tensile strength in specimens after 6-months exposure at New York City and Kure Beach. The "as-cast" specimens were replaced with heat-treated specimens. After 6-months exposure, no significant change had taken place.
EZ33A-T5	At least a 12 per cent loss in tensile strength after 6-months exposure.

The facts presented at this time are for your review. As time goes on, more data will be collected and will justify considerably more statistical study.

Acknowledgment:

The present program, extensive as it is, has been made possible only by the excellent cooperation of the participating members of the society. Acknowledgment is hereby given to all these members who have and will in the future be called on for help.

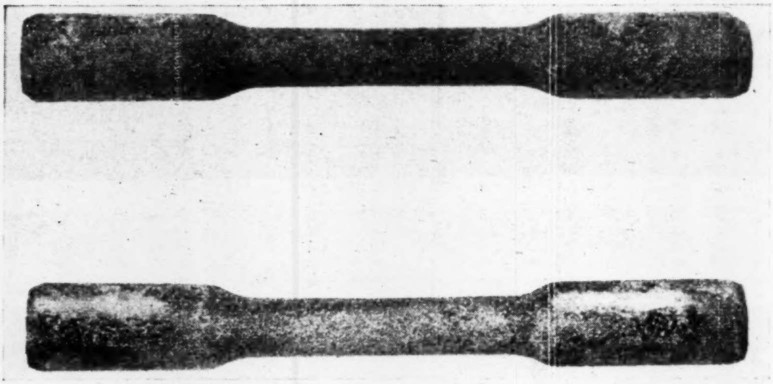


FIG. 3.—Photograph Showing Sand-Cast Tension Specimens—EK30A-T6, After 6-Months Exposure.

Upper casting reveals effects of rural atmosphere, while lower casting represents marine atmospheric effects along the Atlantic Coast.

TABLE II.—CHEMICAL ANALYSES OF MAGNESIUM ALLOY CASTINGS USED IN THE 10-YR ATMOSPHERIC EXPOSURE PROGRAM SPONSORED BY THE ASTM COMMITTEE B-7.

Magnesium Alloys Designations			Chemical Composition, per cent									
Commercial	ASTM		Magnesium	Aluminum	Manganese, min	Zinc	Rare Earth	Zirconium	Silicon	Copper	Nickel	Other Impurities
H or AM265	AZ63A	ASTM Spec[b]	Remainder	5.3 to 6.7	0.15	2.5 to 3.5			0.3	0.25	0.01	0.3
	Sand casting	As Rec'd Values	Remainder	6.17	0.19	3.01			0.03	0.022		
R or AM263	AZ91C	ASTM Spec[b]	Remainder	8.1 to 9.3	0.13	0.4 to 1.0			0.3	0.10	0.01	0.3
	Sand casting T3	As Rec'd Values	Remainder	9.38[a]	0.20	0.69			<0.01	0.02	<0.005	
	F	As Rec'd Values	Remainder	9.35[a]	0.18	0.75			0.02	<0.01	0.003	
C or AM260	AZ92A	ASTM Spec[b]	Remainder	8.3 to 9.7	0.10	1.6 to 2.4			0.3	0.25	0.01	0.3
	Sand casting	As Rec'd Values	Remainder	8.40	0.13	1.95			0.03	0.016		
EK30	EK30A	ASTM Spec[b]	Remainder			0.3	2.5 to 4.0	0.2 min		0.10	0.01	0.3
	Sand casting T6	As Rec'd Values	Remainder	<0.01	0.05	0.21	1.93	0.33	<0.01	<0.01	<0.005	
	F	As Rec'd Values	Remainder	0.07	0.07	<0.05	3.11	0.41	<0.01	<0.01	<0.005	
	EZ33A	ASTM Spec[b]	Remainder			2.0 to 4.0	2.5 to 4.0	0.50 to 1.0		0.10	0.01	0.3
	Sand casting	As Rec'd Values	Remainder	0.05	0.05	2.69	3.24	0.62	<0.01	<0.01		

[a] High.

[b] Tentative Specifications for Magnesium-Base Alloys for Sand Castings, (B 80 – 53 T), 1953 Supplement to ASTM Standards, Part 2, p. 130.

NOTE 1.—When single units are shown in ASTM Specifications, these indicate the maximum amount permitted.

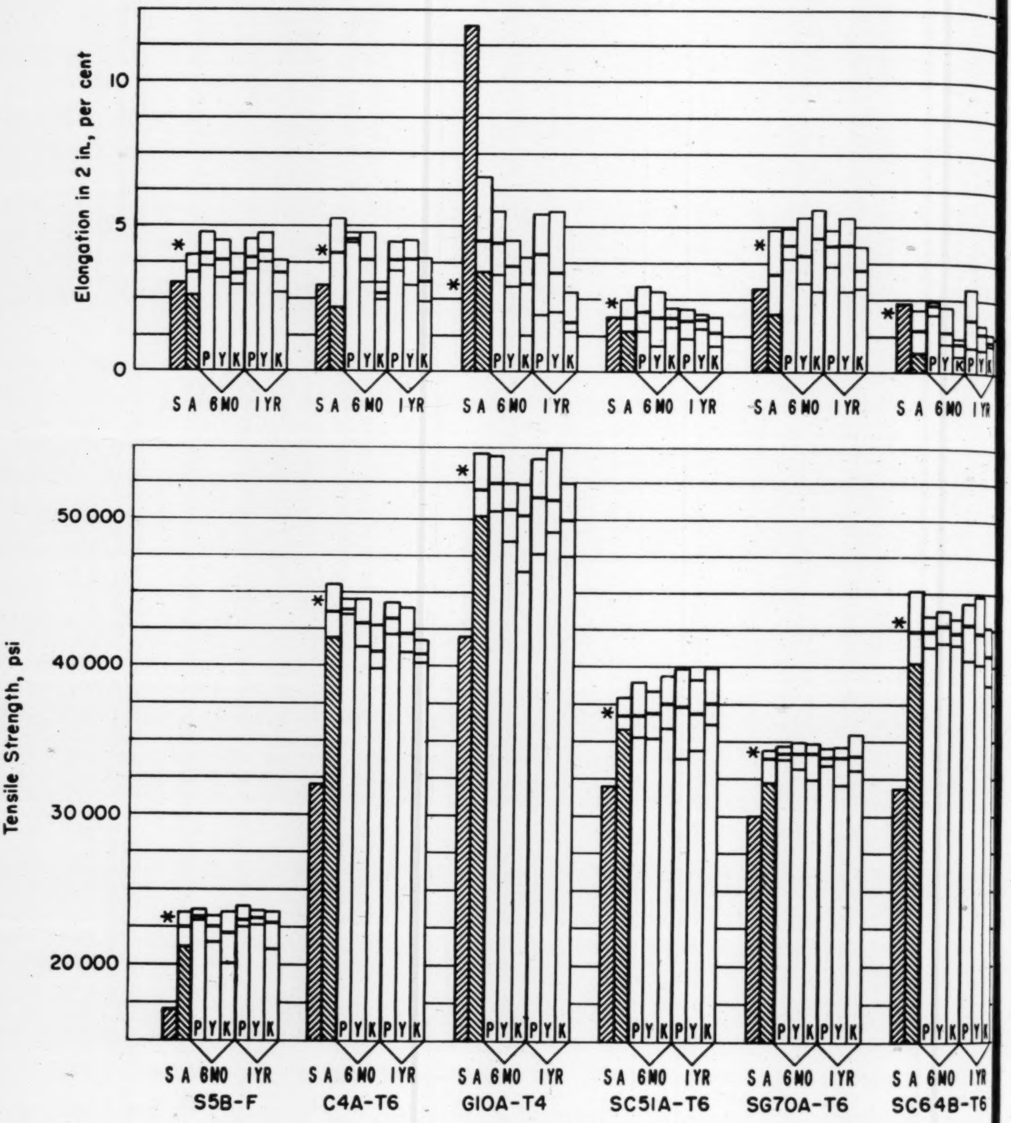
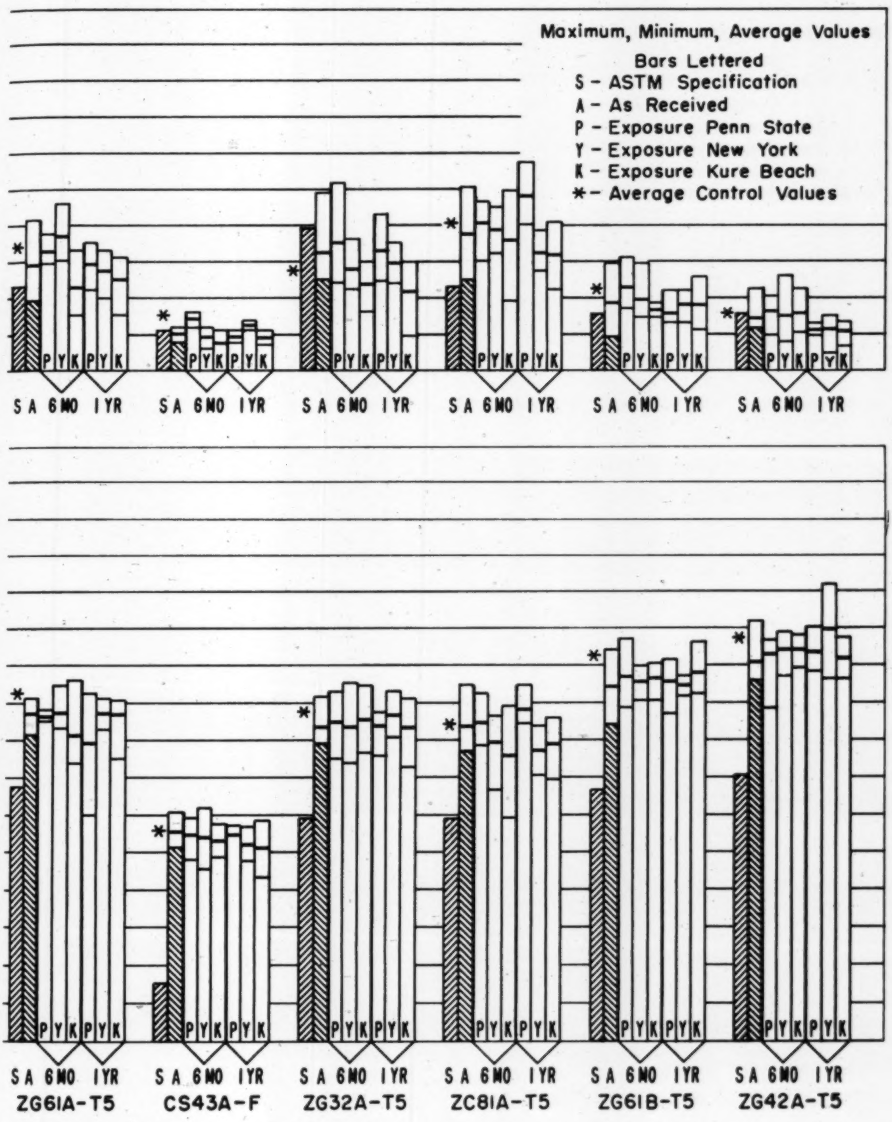
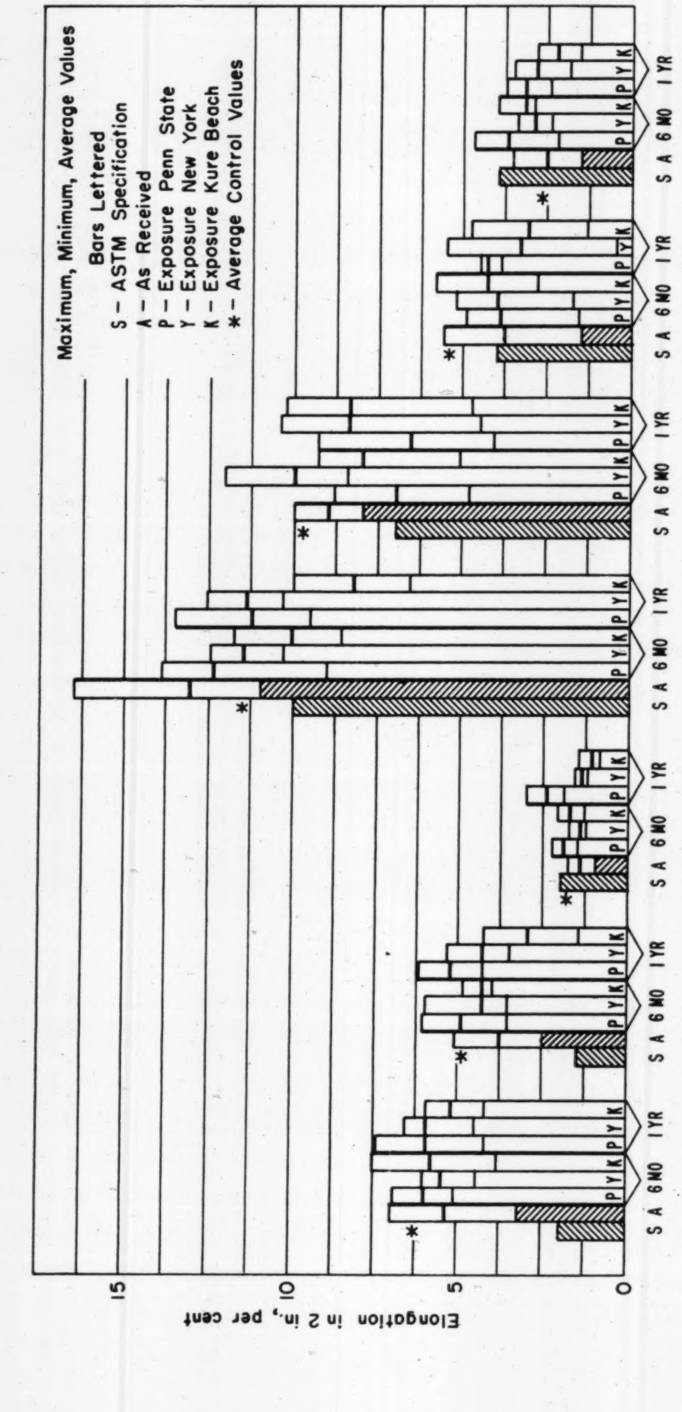


FIG. 4.—Summary of Data on Atmospheric Exposure of



Light Metals and Alloys—Aluminum-Alloy Sand Castings.


Maximum, Minimum, Average Values
Bars Lettered
S – ASTM Specification
A – As Received
P – Exposure Penn State
Y – Exposure New York
K – Exposure Kure Beach
* – Average Control Values
Elongation in 2 in., per cent
0
5
10
15
S A 6 MO 1 YR
P Y K P Y K

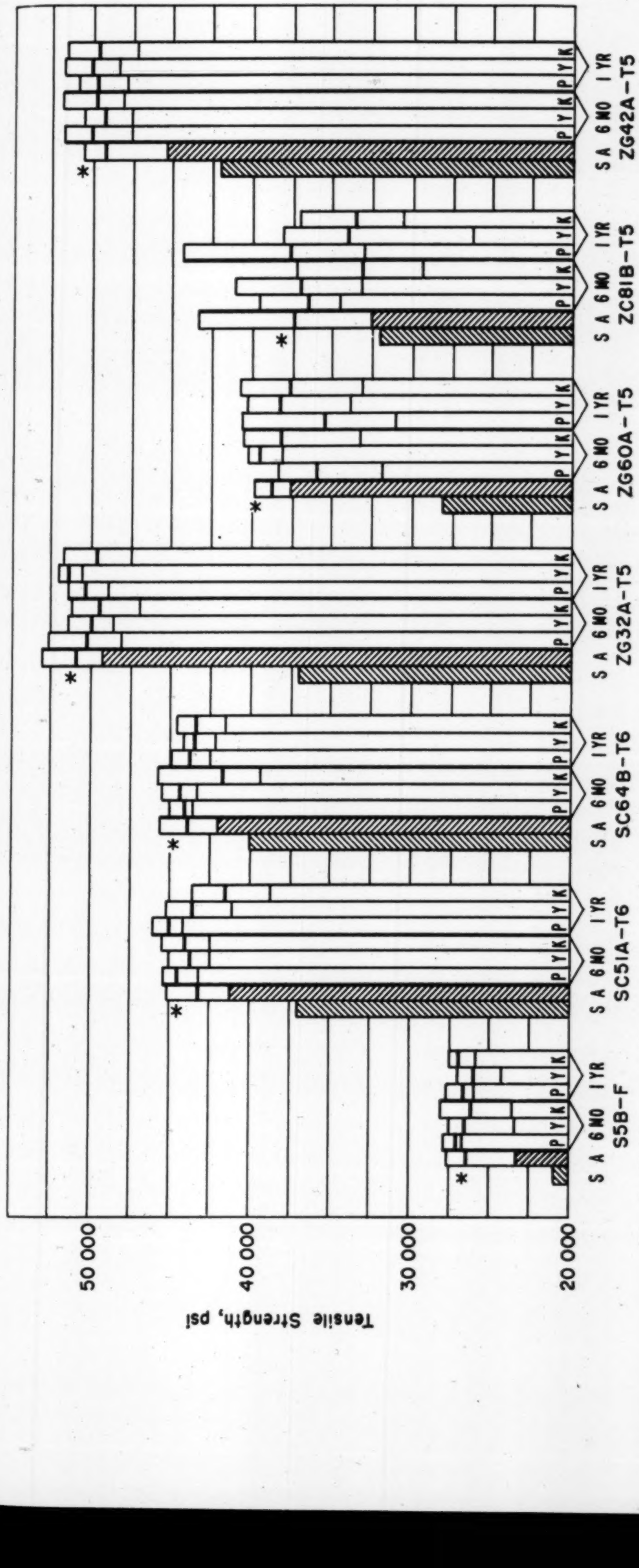
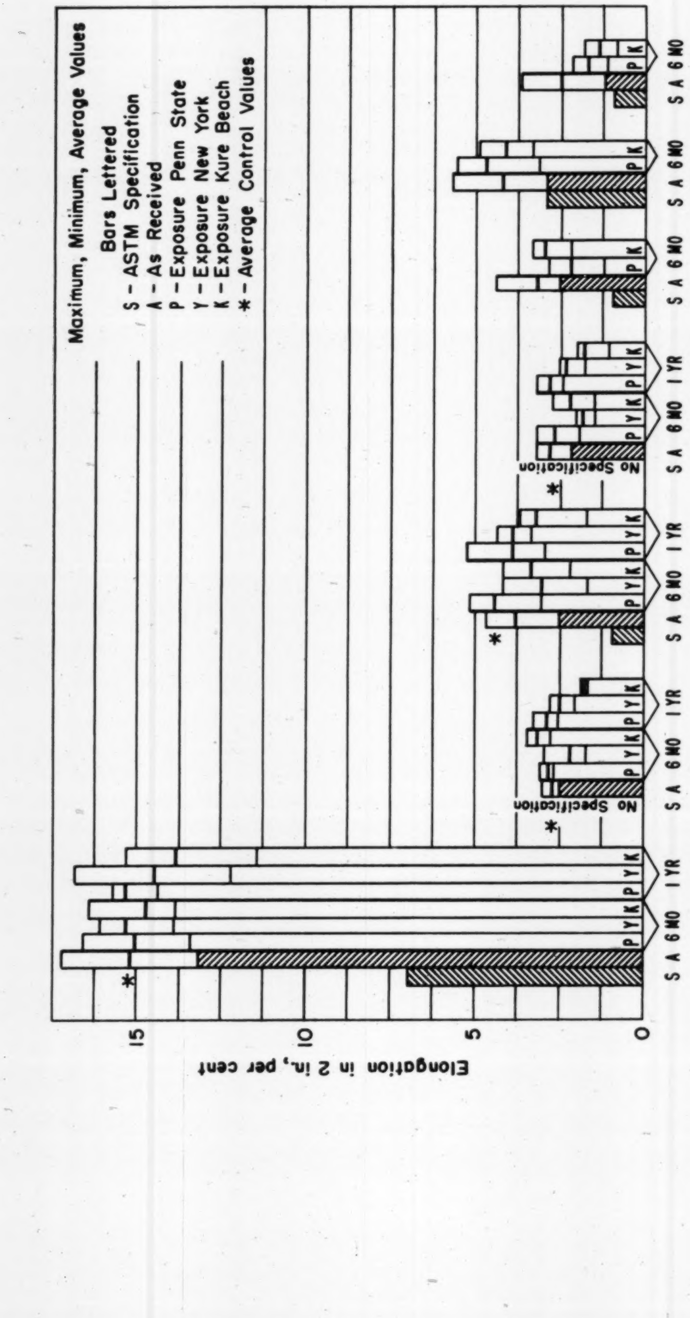


FIG. 5.—Summary of Data on Atmospheric Exposure of Light Metals and Alloys—Aluminum-Alloy Permanent-Mold Castings.


Maximum, Minimum, Average Values
Bars Lettered
S - ASTM Specification
A - As Received
P - Exposure Penn State
Y - Exposure New York
K - Exposure Kure Beach
* - Average Control Values
Elongation in 2 in., per cent
0
5
10
15
S A 6 MO 1 YR
P Y K P Y K
No Specification
S A 6 MO 1 YR
P Y K P Y K
S A 6 MO 1 YR
P Y K P Y K
No Specification
S A 6 MO 1 YR
P Y K P Y K
S A 6 MO
P K
S A 6 MO
P K
S A 6 MO
P K

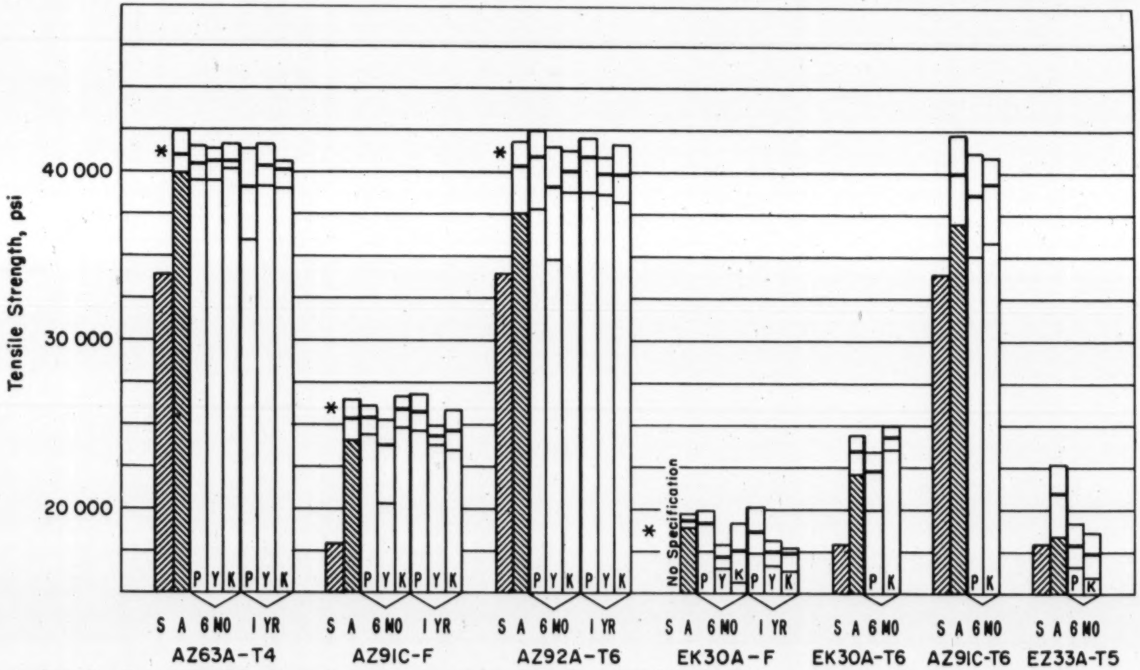


FIG. 6.—Summary of Data on Atmospheric Exposure of Light Metals and Alloys—Magnesium-Alloy Sand Castings.

TABLE III.—DATA ON ALUMINUM ALLOY NO. S5B-F, SAND CASTING.

ASTM Specification Requirements	As Received	6-months Exposure			1-yr Exposure		
		Penn State	New York	Kure Beach	Penn State	New York	Kure Beach
YIELD STRENGTH, 0.2 PER CENT OFFSET, PSI							
7000 psi, min	12 100	13 600	11 400	12 000	11 400	11 900	11 800
	12 700	13 800	11 300	12 300	10 900	11 200	12 200
	11 800	12 000	11 400	11 700	11 000	11 200	12 900
	12 200	12 400	11 000	12 100	11 900	10 700	11 700
	12 300	12 600	11 000	12 800	11 200	11 600	12 000
			10 300	12 800	11 300	11 100	11 800
Average	12 200	12 900	11 100	12 300	11 300	11 300	12 100
TENSILE STRENGTH, PSI							
17 000 psi, min	23 300	22 900	21 400	23 500	23 000	22 600	23 400
	21 100	23 300	23 100	22 900	22 900	23 300	21 000
	23 200	22 800	22 700	20 000	22 900	23 600	23 500
	23 100	23 600	22 900	21 900	23 900	23 000	23 100
	21 900	23 100	22 800	21 300	22 400	23 400	23 100
	23 400	23 200	22 500	22 800	22 600	23 100	23 300
	22 400						
Average	22 600	23 200	22 600	22 100	23 000	23 200	22 900
ELONGATION IN 2 IN., PER CENT							
3.0 per cent, min	3.8	4.1	3.3	4.0	4.3	3.7	3.8
	2.6[a]	3.9	4.4	3.9	4.4	3.8	2.7[a]
	3.9	4.2	4.0	2.9[a]	3.8	4.7	3.8
	3.9	4.7	3.3	3.1	4.5	4.5	3.8
	3.7	3.6	3.5	3.3	3.5	4.4	3.4
	3.7	4.2	4.4	3.4	3 5	3.9	3.4
	3.0						
Average	3.5	4.1	3.8	3.4	4.0	4.2	3.5

[a] Low.

NOTE.—All specifications on aluminum alloy sand castings include Table II of ASTM Specifications B 26 – 54 T, 1954 Supplement to Book of ASTM Standards, Part 2.

TABLE IV.—DATA ON ALUMINUM ALLOY NO. C4A-T6, SAND CASTING.

ASTM Specification Requirements	As Received	6-months Exposure			1-yr Exposure		
		Penn State	New York	Kure Beach	Penn State	New York	Kure Beach
YIELD STRENGTH, 0.2 PER CENT OFFSET, PSI							
20 000 psi, min	30 400	32 800	32 000		31 600	32 000	32 000
	31 000	32 100	30 900	31 800	31 800	31 500	31 400
	31 500	31 200	31 300	31 200	30 500	31 100	31 500
	29 900	31 600	31 000	30 200	31 000	31 200	31 000
	30 500	32 200	31 100	31 400	32 400		31 600
			31 300	31 300	31 500	31 900	32 100
Average	30 700	32 000	31 300	31 200	31 500	31 500	31 600
TENSILE STRENGTH, PSI							
32 000 psi, min	42 200	43 300	42 600	40 600	43 600	43 900	40 100
	45 400	44 000	44 400	42 600	43 200	42 700	41 100
	43 800	43 700	44 000	41 500	42 700	42 900	41 200
	44 200	44 200	41 900	39 800	42 100	41 100	40 600
	43 600	44 400	41 200	40 500	43 400	41 900	40 100
	44 700	43 500	43 500	41 200	44 200	40 900	41 700
	41 800						
Average	43 700	43 900	42 900	41 000	43 200	42 200	40 800
ELONGATION IN 2 IN., PER CENT							
3.0 per cent, min	2.2[a]	4.4	4.0	2.6[a]	4.2	4.6	2.4[a]
	5.0	4.5	4.8	3.0	4.4	3.9	3.2
	3.0	4.6	4.0	3.1	3.5	4.5	2.9[a]
	4.9	4.7	3.4	2.5[a]	3.6	3.7	3 9
	5.3	4.6	3.1	2.5[a]	3.8	3.5	3.2
	4.6	4.8	4.0	3.1	4.1	3.0	3.3
	3.7						
Average	4.1	4.6	3.9	2.8[a]	3.9	3.9	3.2

[a] Low.

TABLE V.—DATA ON ALUMINUM ALLOY NO. G10A-T4, SAND CASTING.

ASTM Specification Requirements	As Received	6-months Exposure			1-yr Exposure		
		Penn State	New York	Kure Beach	Penn State	New York	Kure Beach
YIELD STRENGTH, 0.2 PER CENT OFFSET, PSI							
22 000 psi, min	38 300	40 800	39 000	41 000	41 200	41 500	37 800
	40 500	39 800	38 700	41 900	43 000	39 700	36 900
	39 400	39 700	40 100	40 800	39 400	39 900	42 500
	37 200	41 000	39 600	40 200	38 900	40 400	40 700
	39 500	39 900	38 000		40 100	40 200	43 200
			40 200	41 600	40 200		37 500
Average	39 000	40 200	39 300	41 100	40 500	40 300	39 800
TENSILE STRENGTH, PSI							
42 000 psi, min	51 900	54 400	52 400	50 600	52 900	52 000	52 500
	54 500	53 300	49 300	46 300	54 200	52 600	47 400
	50 200	50 600	51 500	51 300	51 000	49 900	50 500
	51 700	52 400	51 000	50 200	51 900	50 600	49 600
	51 300	51 800	48 400	52 400	52 100	49 100	51 300
	53 500	52 500	51 700	51 500	47 600	54 800	49 300
	51 500						
Average	52 100	52 500	50 700	50 400	51 600	51 500	50 100
ELONGATION IN 2 IN., PER CENT							
12.0 per cent, min	4.9[a]	5.6[a]	4.6[a]	2.9[a]	4.5[a]	3.3[a]	2.8[a]
	6.7[a]	4.8[a]	4.0[a]	1.3[a]	3.4[a]	5.1[a]	1.6[a]
	4.3[a]	3.3[a]	3.0[a]	4.0[a]	4.3[a]	2.2[a]	1.6[a]
	3.5[a]	4.0[a]	3.4[a]	3.0[a]	5.5[a]	2.1[a]	1.5[a]
	4.7[a]	4.3[a]	3.3[a]	3.7[a]	4.7[a]	2.4[a]	1.8[a]
	4.6[a]	4.9[a]	3.8[a]	3.4[a]	2.0[a]	5.6[a]	1.4[a]
	3.6[a]						
Average	4.6[a]	4.5[a]	3.7[a]	3.1[a]	4.1[a]	3.5[a]	1.8[a]

[a] Low.

TABLE VI.—DATA ON ALUMINUM ALLOY NO. SC51A-T6, SAND CASTING.

ASTM Specification Requirements	As Received	6-months Exposure			1-yr Exposure		
		Penn State	New York	Kure Beach	Penn State	New York	Kure Beach
YIELD STRENGTH, 0.2 PER CENT OFFSET, PSI							
20 000 psi, min	28 100	27 200	28 100	30 400	29 500		29 500
	29 400	25 900	27 900	32 900	30 100	28 900	29 300
	28 700	26 100	28 900	29 100	28 700	27 300	29 300
	28 300	27 300	29 300	30 000	29 200	28 900	
	27 200	26 100	31 000	29 700	32 300	31 200	29 000
			30 000	32 600	29 700	29 600	29 600
Average	28 300	26 500	29 200	30 800	29 900	29 200	29 300
TENSILE STRENGTH, PSI							
32 000 psi, min	35 700	38 600	36 300	37 800	33 900	37 000	36 500
	36 500	36 300	36 200	39 400	37 900	36 300	36 200
	37 700	35 200	38 400	35 900	37 300	35 600	38 100
	38 100	39 000	37 900	36 700	38 100	34 400	40 000
	35 900	36 400	38 200	37 900	39 900	38 700	36 700
	36 400	35 300	35 300	38 800	36 500	39 200	38 200
	37 200						
Average	36 800	36 800	37 100	37 700	37 300	36 900	37 600
ELONGATION IN 2 IN., PER CENT							
2.0 per cent, min	1.6[a]	2.4	2.0	2.1	1.2[a]	2.0	1.2[a]
	1.6[a]	1.7[a]	2.2	1.6[a]	2.3	2.1	1.9[a]
	2.0	2.1	2.8	1.7[a]	2.1	1.6[a]	2.0
	2.6	3.1	1.8[a]	2.3	2.1	1.9[a]	1.0[a]
	1.5[a]	2.6	1.9[a]	2.0	1.7[a]	2.0	1.7[a]
	1.8[a]	1.5[a]	1.0[a]	2.1	1.5[a]	2.0	1.2[a]
	2.3						
Average	1.9[a]	2.2	2.0	2.0	1.8[a]	1.9[a]	1.5[a]

[a] Low.

TABLE VII.—DATA ON ALUMINUM ALLOY NO. SG70A-T6, SAND CASTING.

ASTM Specification Requirements	As Received	6-months Exposure			1-yr Exposure		
		Penn State	New York	Kure Beach	Penn State	New York	Kure Beach
YIELD STRENGTH, 0.2 PER CENT OFFSET, PSI							
20 000 psi, min	25 600	25 000	24 500	26 700	25 600	24 900	24 300
	24 100	24 900	25 100	26 000	24 600	25 100	24 700
	24 500	25 400	23 800	25 000	24 300	24 600	24 900
	24 200	24 000	24 100	24 600	24 500	25 200	26 000
	25 600		25 800	26 600	26 000	24 500	26 200
		25 300	26 100	24 600	25 400	24 800	26 200
Average	24 800	24 900	24 900	25 600	25 100	24 800	25 400
TENSILE STRENGTH, PSI							
30 000 psi, min	34 400	33 900	35 100	35 400	34 700	34 800	33 200
	34 500	34 100	34 700	34 500	34 100	34 400	34 000
	34 200	34 300	33 200	35 100	33 500	32 200	34 200
	34 100	34 100	34 300	34 800	33 900	34 500	33 700
	34 400	34 600	34 600	32 500	34 400	34 600	34 100
	33 900	34 800	34 100	34 300	34 100	33 200	35 600
	32 300						
Average	34 000	34 300	34 300	34 400	34 100	34 000	34 100
ELONGATION IN 2 IN., PER CENT							
3.0 per cent, min	5.0	4.1	5.0	4.6	3.7	5.4	3.7
	4.2	4.0	3.5	3.9	5.0	4.8	3.7
	3.4	4.6	3.3	5.5	4.5	2.9[a]	3.9
	3.4	5.1	3.2	5.7	4.9	4.7	3.0
	4.1	4.1	3.9	2.9[a]	4.1	5.1	3.1
	2.5[a]	4.3	5.4	5.6	4.0	3.5	4.4
	2.1[a]						
Average	3.5	4.4	4.1	4.7	4.4	4.4	3.6

[a] Low.

TABLE VIII.—DATA ON ALUMINUM ALLOY NO. SC64B-T6, SAND CASTING.

ASTM Specification Requirements	As Received	6-months Exposure			1-yr Exposure		
		Penn State	New York	Kure Beach	Penn State	New York	Kure Beach
YIELD STRENGTH, 0.2 PER CENT OFFSET, PSI							
20 000 psi, min	32 800	33 400	34 100	36 100	32 200	34 500	
	34 300	34 000	33 300	35 400	33 000	32 900	
	33 500	33 300	32 900	36 000	33 200		32 400
	33 400	33 700	33 900	36 900	34 900	34 700	33 100
	34 600	33 400	33 900	36 500	33 700	33 200	33 800
			33 400	34 200	34 400		33 900
Average	33 700	33 600	33 600	35 800	33 600	33 800	33 300
TENSILE STRENGTH, PSI							
32 000 psi, min	43 300	43 600	43 600	42 900	43 300	45 000	41 500
	41 300	43 400	42 600	43 300	43 000	40 300	42 800
	42 800		43 900	42 200	43 600	41 900	39 200
	43 600	42 800	44 000	43 100	43 200	43 000	42 100
	40 400	42 000	41 800	42 500	44 500	42 400	41 500
	42 900	41 600	42 500	41 700	40 600		38 900
	45 300						
Average	42 800	42 700	43 100	42 600	43 000	42 500	41 000
ELONGATION IN 2 IN., PER CENT							
2.5 per cent, min	1.6[a]	2.6	1.6[a]	1.3[a]	3.0	1.7[a]	1.5[a]
	1.4[a]	2.1[a]	1.1[a]	1.0[a]	1.8[a]	1.6[a]	1.2[a]
	2.3[a]		1.5[a]	1.0[a]	1.0[a]	1.5[a]	1.1[a]
	1.4[a]	2.4[a]	1.5[a]	1.3[a]	1.6[a]	1.8[a]	1.2[a]
	0.8[a]	2.6	1.2[a]	1.1[a]	2.5	0.9[a]	1.2[a]
	1.5[a]	2.2[a]	2.2[a]	0.7[a]	1.3[a]		1.1[a]
	2.2[a]						
Average	1.6[a]	2.4[a]	1.5[a]	1.1[a]	1.9[a]	1.5[a]	1.2[a]

[a] Low.

TABLE IX.—DATA ON ALUMINUM ALLOY NO. ZG61A-T5, SAND CASTING.

ASTM Specification Requirements	As Received	6-months Exposure			1-yr Exposure		
		Penn State	New York	Kure Beach	Penn State	New York	Kure Beach
YIELD STRENGTH, 0.2 PER CENT OFFSET, PSI							
22 000 psi, min	27 600		29 900	29 000	29 400	28 200	27 800
	28 300	28 600	28 500	27 900	29 000	30 400	29 600
	27 400	28 500	31 800	28 700	28 300	29 400	30 200
	28 200	30 800	29 800	30 000	28 900	28 500	30 300
	26 800	28 700	29 600	29 200	28 800	29 700	29 800
		28 800	28 300	29 100	28 400		27 900
Average	27 700	29 100	29 700	29 000	28 800	29 200	29 300
TENSILE STRENGTH, PSI							
32 000 psi, min	35 700	36 400	36 700	36 000	38 300	36 200	33 900
		36 400	36 000	33 600	31 700	38 000	36 500
	37 900	37 000	38 900	34 500	37 000	37 500	36 700
	38 000	36 900	37 600	39 200	36 700	37 200	37 900
	36 900	37 300	36 600	35 900	35 800	35 900	37 600
	37 700	37 200	36 100	33 700	30 100		37 700
	35 600						
Average	37 000	36 900	37 000	35 500	35 000	37 000	36 700
ELONGATION IN 2 IN., PER CENT							
3.0 per cent, min	2.5[a]	3.8	5.0	4.1	3.5	4.2	2.2[a]
		[b]	5.8	3.1	4.5	2.7[a]	2.7[a]
	5.3	4.3	4.5	2.3[a]	4.5	3.9	2.8[a]
	3.6	3.8	4.4	4.2	3.7	4.0	3.6
	4.1	4.8	4.3	2.4[a]	2.9[a]	2.6[a]	4.0
	3.3	4.7	3.9	2.0[a]	2.9[a]		3.8
	3.3						
Average	3.7	4.3	4.7	3.0	3.7	3.5	3.2

[a] Low.
[b] Double break at fracture.

TABLE X.—DATA ON ALUMINUM ALLOY NO. CS43A-F, SAND CASTING.

ASTM Specification Requirements	As Received	6-months Exposure			1-yr Exposure		
		Penn State	New York	Kure Beach	Penn State	New York	Kure Beach
YIELD STRENGTH, 0.2 PER CENT OFFSET, PSI							
12 000 psi, min	22 800	22 400	22 100	23 600	22 400	21 000	22 600
	22 600	23 000	22 300	22 600	23 000	22 100	23 500
	24 200	23 000	22 500	23 400	22 600	22 500	22 700
	23 000	21 800	21 700	24 100	22 200	21 600	22 100
	22 600	23 300	21 600	23 200	22 900	22 100	22 100
				23 800	22 400	21 900	22 200
Average	23 000	22 700	22 000	23 500	22 600	21 900	22 500
TENSILE STRENGTH, PSI							
19 000 psi, min	28 800	28 900	29 300	28 300	29 500	27 100	28 100
	29 400	29 900	30 700	28 200	29 500	27 200	29 800
	28 900	29 000	29 000	28 500	28 700	29 400	29 600
	28 000	28 000	26 500	28 500	28 200	27 500	25 900
	30 400	27 200	27 800	27 300	28 700	29 200	27 100
	28 700	29 800		29 600	28 400	28 300	27 000
Average	29 000	28 800	28 700	28 400	28 800	28 100	27 900
ELONGATION IN 2 IN., PER CENT							
1.5 per cent, min	1.2[a]	2.0	1.5	1.5	1.5	1.6	1.2[a]
	1.1[a]	1.9	1.6	1.1[a]	1.3[a]	1.7	1.5
	1.5	1.9	1.2[a]	1.1[a]	1.2[a]	1.8	1.4[a]
	1.5	1.7	0.8[a]	1.5	1.2[a]	1.5	1.2[a]
	1.6	1.6	1.2[a]	1.3[a]	1.2[a]	1.8	1.0[a]
	1.5	2.1		1.3[a]	1.1[a]	1.5	1.4[a]
Average	1.4[a]	1.9	1.3[a]	1.3[a]	1.3[a]	1.7	1.3[a]

[a] Low.

TABLE XI.—DATA ON ALUMINUM ALLOY NO. ZG32A-T5, SAND CASTING.

ASTM Specification Requirements	As Received	6-months Exposure			1-yr Exposure		
		Penn State	New York	Kure Beach	Penn State	New York	Kure Beach
YIELD STRENGTH, 0.2 PER CENT OFFSET, PSI							
17 000 psi, min	27 700	25 500	28 300	32 200	27 600	29 200	29 800
	27 000	27 300	28 100	29 500	28 400	27 200	27 300
	26 200	28 000	28 300	27 500	28 100	28 400	28 700
	28 000	27 200	27 300	30 700	26 900	29 100	30 000
	28 000	27 800	27 700	29 900	28 600	28 800	29 200
			28 400	29 200	27 300		29 800
Average	27 400	27 200	28 000	29 800	27 800	28 500	29 100
TENSILE STRENGTH, PSI							
30 000 psi, min	36 800	34 200	35 400	36 000	36 600	38 600	37 100
	35 000	36 000	35 100	38 900	36 000	36 200	34 800
	35 200	38 300	37 000	34 400	36 500	37 600	37 100
	38 200	34 000	39 100	36 900	36 900	36 500	38 100
	35 600	37 500	36 500	38 100	37 100	35 400	36 100
	35 800	38 500	33 700	35 200	34 200		33 400
	36 200						
Average	36 100	36 400	36 100	36 600	36 200	36 900	36 100
ELONGATION IN 2 IN., PER CENT							
5.0 per cent, min	5.1	3.5[a]	3.0[a]	2.8[a]	5.0	4.5[a]	2.6[a]
	3.2[a]	4.7[a]	3.6[a]	3.8[a]	3.3[a]	4.1[a]	3.1[a]
	3.2[a]	4.8[a]	3.7[a]	2.9[a]	4.2[a]	4.3[a]	3.8[a]
	6.2	3.4[a]	3.6[a]	3.4[a]	5.5	3.1[a]	3.1[a]
	4.0[a]	3.1[a]	4.6[a]	3.7[a]	4.1[a]	3.1[a]	2.7[a]
	3.6[a]	6.6	2.9[a]	2.1[a]	3.5[a]		1.3[a]
	3.5[a]						
Average	4.1[a]	4.4[a]	3.6[a]	3.1[a]	4.3[a]	3.8[a]	2.8[a]

[a] Low.

TABLE XII.—DATA ON ALUMINUM ALLOY NO. ZC81A-T5, SAND CASTING.

ASTM Specification Requirements	As Received	6-months Exposure			1-yr Exposure		
		Penn State	New York	Kure Beach	Penn State	New York	Kure Beach
YIELD STRENGTH, 0.2 PER CENT OFFSET, PSI							
22 000 psi, min	25 500	28 300	26 100	31 900	26 400	26 000	27 700
	25 700	28 600	25 200	27 800	26 100	25 600	26 800
	26 000	28 200	25 600	28 800	25 500	25 600	25 500
	26 000	27 600	24 500	30 000	26 200	26 200	25 900
	25 200	28 800	25 800	27 400	25 800	25 700	24 600
			24 200	26 800	26 300	26 100	26 100
Average	25 700	28 300	25 200	28 800	26 000	25 900	26 100
TENSILE STRENGTH, PSI							
30 000 psi, min	34 500	35 900	36 800	30 000	39 000	34 700	34 800
	35 300	34 800	35 800	34 200	36 700	33 800	36 800
	34 700	36 400	34 600	34 500	37 600	36 200	36 100
	36 300	35 800	35 600	33 700	37 000	34 800	32 600
	36 700	37 000	31 900	37 500	37 300	32 900	34 300
	39 000	38 400	35 700	35 300	36 400	35 400	35 400
	36 500						
Average	36 100	36 400	35 100	34 200	37 300	34 600	35 000
ELONGATION IN 2 IN., PER CENT							
3.0 per cent, min	3.3	5.7	5.4	2.4[a]	7.3	3.8	3.6
	5.3	5.3	5.3	3.5	5.7	3.7	4.6
	3.2	3.9	4.1	5.6	5.9	4.9	5.2
	4.5	4.7	5.2	4.9	6.0	4.0	2.8[a]
	5.2	5.9	3.6	6.3	6.3	3.5	4.0
	6.4	5.6	5.7	4.7	5.1	4.9	4.0
	5.8						
Average	4.8	5.2	4.9	4.6	6.1	4.1	4.0

[a] Low.

TABLE XIII.—DATA ON ALUMINUM ALLOY NO. ZG61B-T5, SAND CASTING.

ASTM Specification Requirements	As Received	6-months Exposure			1-yr Exposure		
		Penn State	New York	Kure Beach	Penn State	New York	Kure Beach
	YIELD STRENGTH, 0.2 PER CENT OFFSET, PSI						
20 000 psi, min	32 200		33 100	38 200	33 200	30 700	35 200
	32 200	32 500	32 100	36 500	32 400	31 000	33 000
	31 600	33 800	32 500	34 000	32 100	31 000	33 800
	31 400	32 800	33 200	33 900	33 400	32 900	33 500
	32 500	32 300	32 400		32 700		32 800
		32 500	34 900	32 900	33 700		31 600
Average	32 000	32 800	33 000	35 100	32 900	31 400	33 300
	TENSILE STRENGTH, PSI						
32 000 psi, min	41 400	39 600	40 200	40 500	40 300	38 300	42 000
	39 100	39 200	40 000	39 300	38 700	39 400	38 400
	38 500	39 100	38 000	38 700	37 100	38 600	39 900
	36 400	42 200	38 500	40 100	40 800	38 400	40 300
	37 200	37 500	38 500	38 000	38 100	39 700	38 500
	37 000	39 700	40 100	39 700	40 000		39 700
	41 400						
Average	38 700	39 500	39 200	39 400	39 200	38 900	39 800
	ELONGATION IN 2 IN., PER CENT						
2.0 per cent, min	3.7	2.6	3.7	2.3	2.0	2.3	3.3
	2.8	2.9	2.2	2.2	1.8[a]	2.8	1.4[a]
	2.7	2.8	2.1	2.4	1.7[a]	1.9[a]	2.7
	1.2[a]	4.0	1.9[a]	2.1	2.8	1.8[a]	2.7
	1.8[a]	2.2	2.8	1.9[a]	1.8[a]	2.9	1.6[a]
	1.7[a]	3.0	2.5	2.4	2.1		1.9[a]
	2.6						
Average	2.4	2.9	2.5	2.2	2.0	2.3	2.3

[a] Low.

TABLE XIV.—DATA ON ALUMINUM ALLOY NO. ZG42A-T5, SAND CASTING.

ASTM Specification Requirements	As Received	6-months Exposure			1-yr Exposure		
		Penn State	New York	Kure Beach	Penn State	New York	Kure Beach
	YIELD STRENGTH, 0.2 PER CENT OFFSET, PSI						
22 000 psi, min	35 100	35 600	36 700		36 600	36 700	36 900
	35 200	35 600	35 700	36 500	36 100	35 900	37 200
	34 400	35 400	35 200	36 100	35 700	35 200	37 000
	35 000	35 000	35 200	36 100	36 200	36 000	35 900
	35 200	35 400	36 000		35 500	36 800	37 400
			35 500	36 500	36 200		36 200
Average	35 000	35 400	35 700	36 300	36 100	36 100	36 800
	TENSILE STRENGTH, PSI						
33 000 psi, min	39 800	41 600	42 600	41 100	42 900	43 100	40 400
	39 300	41 900	39 700	42 000	40 000	39 500	41 000
	41 200	37 500	41 800	41 600	40 800	45 800	39 800
	43 300	42 100	41 900	40 100	41 300	43 000	40 800
	39 500	41 800	42 100	40 800	40 300	42 000	42 200
	40 000	41 500	40 100	42 300	41 900		40 300
	41 400						
Average	40 600	41 100	41 400	41 300	41 200	42 700	40 800
	ELONGATION IN 2 IN., PER CENT						
2.0 per cent, min	1.6[a]	2.1	3.3	1.8[a]	1.6[a]	1.8[a]	1.2[a]
	1.4[a]	2.6	1.0[a]	2.8	1.4[a]	1.2[a]	1.4[a]
	2.0	1.2[a]	1.9[a]	1.4[a]	1.3[a]	0.5[a]	0.8[a]
	2.8	2.2	1.6[a]	2.5	1.2[a]	1.5[a]	1.7[a]
	1.0[a]	2.4	1.7[a]	1.3[a]	1.3[a]	1.9[a]	1.3[a]
	1.6[a]	1.9[a]	2.0	2.0	1.3[a]		1.2[a]
	2.0						
Average	1.8[a]	2.1	1.9[a]	2.0	1.4[a]	1.4[a]	1.3[a]

[a] Low.

TABLE XV.—DATA ON ALUMINUM ALLOY NO. S5B-F, PERMANENT MOLD.

ASTM Specification Requirements	As Received	6-months Exposure			1-yr Exposure		
		Penn State	New York	Kure Beach	Penn State	New York	Kure Beach
YIELD STRENGTH, 0.2 PER CENT OFFSET, PSI							
7 000 psi, min	12 100	11 500	12 000	10 800	11 200	11 200	
	12 500	11 800		13 100	12 400	12 200	12 600
	12 000	11 100	11 900	12 000	12 800	11 100	12 600
	12 100	12 200	11 900	13 300	11 700	11 100	11 800
	12 000	12 700	11 100	13 000	11 700	12 000	11 600
			11 200	12 100	12 700	11 800	12 600
Average	12 100	11 900	11 600	12 400	12 100	11 600	12 200
TENSILE STRENGTH, PSI							
21 000 psi, min	26 900	26 800	27 100	26 600	26 200	26 400	27 700
	27 600	27 700	27 100	23 500	26 300	25 700	26 300
	27 200	26 800	27 500	26 100	27 700	24 200	27 500
	27 000	26 700	27 100	25 800	27 000	25 800	26 700
	27 300	27 800	23 300	27 100	27 100	26 800	25 800
	23 300	26 700	27 300	28 000	25 800	26 900	27 500
	25 700						
Average	26 400	27 100	26 600	26 200	26 700	26 000	26 900
ELONGATION IN 2 IN., PER CENT							
2.0 per cent, min	5.4	5.9	5.8	5.5	5.7	5.9	5.9
	7.0	6.5	5.6	3.8	5.0	6.6	4.5
	6.2	5.4	6.0	5.9	7.4	4.5	5.8
	6.3	6.2	5.6	5.3	6.3	5.9	4.9
	6.0	6.9	4.4	6.0	6.7	6.1	4.2
	3.2	5.1	5.6	7.5	4.2	6.2	5.8
	4.1						
Average	5.4	6.0	5.5	5.7	5.9	5.9	5.2

NOTE.—All specifications on magnesium alloy sand castings include Table II of ASTM Specifications B 108 – 54 T, 1954 Supplement to Book of ASTM Standards, Part 2

TABLE XVI.—DATA ON ALUMINUM ALLOY NO. SC51A-T6, PERMANENT MOLD.

ASTM Specification Requirements	As Received	6-months Exposure			1-yr Exposure		
		Penn State	New York	Kure Beach	Penn State	New York	Kure Beach
YIELD STRENGTH, 0.2 PER CENT OFFSET, PSI							
23 000 psi, min	28 300	30 700		32 200	31 200	30 400	30 900
	32 000	30 400	28 400	28 700	31 600	28 100	30 000
	29 300	27 900	28 200	28 600	27 200	29 500	27 600
	27 600	30 600	27 600	31 700	31 300	27 500	31 400
	31 100	28 600	29 900	31 600	30 800	31 800	31 200
				21 600	28 000		27 400
Average	29 700	29 600	28 500	30 700	30 000	29 500	29 800
TENSILE STRENGTH, PSI							
37 000 psi, min	41 400	44 200	44 300	44 400	44 600	43 900	38 600
	41 200	44 600	44 900	44 000	45 900	44 400	43 500
	41 800	45 200	42 200	43 000	44 100	45 100	42 900
	44 700	43 200	43 900	45 100	44 900	41 300	38 900
	44 400	45 300	43 000	45 400	44 300	43 200	43 300
	43 500	44 500		42 200	45 000		42 000
	45 100						
Average	43 200	44 500	43 700	44 000	44 800	43 600	41 500
ELONGATION IN 2 IN., PER CENT							
1.5 per cent, min	2.5	3.8	4.0	4.2	4.4	3.6	1.4[a]
	2.5	4.8	6.0	4.8	5.9	5.3	3.6
	3.7	6.1	3.6	4.3	6.2	5.3	4.2
	3.9	3.6	3.7	4.0	4.8	3.6	1.8
	4.8	6.0	4.4	4.1	4.3	3.5	3.2
	5.1	5.2		4.2	6.2		3.2
	4.2						
Average	3.8	4.9	4.3	4.3	5.3	4.3	2.9

[a] Low.

TABLE XVII.—DATA ON ALUMINUM ALLOY NO. SC64B-T61, PERMANENT MOLD.

ASTM Specification Requirements	As Received	6-months Exposure			1-yr Exposure		
		Penn State	New York	Kure Beach	Penn State	New York	Kure Beach
YIELD STRENGTH, 0.2 PER CENT OFFSET, PSI							
26 000 psi, min	33 900	34 700	37 200	33 200	34 800	34 000	37 400
	39 300	35 300	34 200	34 100	35 000	36 000	36 600
	35 700	34 600	36 800	34 400	33 700	35 300	35 800
	33 900	34 500	35 800		35 400	35 700	34 100
		34 200	35 500	33 700	33 800	35 300	37 400
			34 900	34 900			37 100
Average	35 700	34 700	35 700	34 100	34 500	35 300	36 400
TENSILE STRENGTH, PSI							
40 000 psi, min	41 900	43 700	44 800	39 800	44 600	43 300	44 500
	43 800	44 800	43 600	40 900	43 800	44 100	41 700
	43 500	44 200	45 400	41 800	42 300	43 800	43 100
	45 600	43 800	43 800	42 600	44 600	42 200	41 500
	44 900	43 500	44 700	39 300	42 400	43 700	44 400
	43 300	44 700	43 200	45 700	44 800		44 400
Average	43 800	44 100	44 300	41 700	43 700	43 400	43 300
ELONGATION IN 2 IN., PER CENT							
2.0 per cent, min	1.1[a]	1.9[a]	1.3[a]	2.1	2.3	1.3[a]	0.8[a]
	1.7[a]	1.9[a]	1.6[a]	1.3[a]	3.0	1.2[a]	1.0[a]
	1.7[a]	1.9[a]	1.7[a]	1.7[a]	2.4	1.2[a]	0.9[a]
	1.0[a]	2.2	1.4[a]	1.6[a]	2.8	1.6[a]	1.5[a]
	1.7[a]	1.5[a]	1.3[a]	1.8[a]	2.0	1.5[a]	1.1[a]
	1.7[a]	1.8[a]	1.2[a]	1.9[a]	1.9[a]		1.0[a]
	0.9[a]						
Average	1.4[a]	1.9[a]	1.4[a]	1.7[a]	2.4	1.4[a]	1.0[a]

[a] Low.

TABLE XVIII.—DATA ON ALUMINUM ALLOY NO. ZG32A-T5, PERMANENT MOLD.

ASTM Specification Requirements	As Received	6-months Exposure			1-yr Exposure		
		Penn State	New York	Kure Beach	Penn State	New York	Kure Beach
YIELD STRENGTH, 0.2 PER CENT OFFSET, PSI							
17 000 psi, min	30 700	31 200	32 500	31 900	31 400	32 800	33 400
	32 300	30 900	31 400	34 000	31 400	33 800	32 800
	31 000	31 000	31 300	30 900	31 400		32 700
	31 900	32 500	32 700	32 600	32 200		33 400
	31 000	30 800	31 700	31 700	31 500		32 500
			31 200	31 700	32 100	32 500	32 700
Average	31 400	31 300	31 800	32 100	31 700	33 000	32 900
TENSILE STRENGTH, PSI							
37 000 psi, min	50 700	51 000	50 400	46 900	50 600	51 400	51 700
	50 900	50 100	49 700	50 800	51 300	51 900	48 300
	50 900	49 200	48 500	48 800	48 800	51 100	48 100
	52 900	52 600	51 300	51 100	50 900	52 000	51 700
	50 400	50 100	50 100	50 900	50 900	50 400	50 200
	50 500	48 000	49 200	48 000	49 400	50 900	47 300
	49 200						
Average	50 800	50 200	49 900	49 400	50 300	51 300	49 600
ELONGATION IN 2 IN., PER CENT							
10.0 per cent, min	16.5	13.1	11.5	7.3[a]	10.8	10.6	10.0
	11.5	13.6	11.4	10.3	12.9	10.9	7.3[a]
	14.7	12.0	10.3	10.5	9.6[a]	12.1	7.2[a]
	14.2	13.9	12.2	11.5	11.1	12.6	10.0
	12.5	12.4	12.2	11.7	13.5	12.0	9.6[a]
	11.3	9.0[a]	11.2	9.4[a]	9.5[a]	10.4	6.6[a]
	11.0						
Average	13.1	12.3	11.5	10.1	11.2	11.4	8.4[a]

[a] Low.

TABLE XIX.—DATA ON ALUMINUM ALLOY NO. ZG60A-T5, PERMANENT MOLD.

ASTM Specification Requirements	As Received	6-months Exposure			1-yr Exposure		
		Penn State	New York	Kure Beach	Penn State	New York	Kure Beach
YIELD STRENGTH, 0.2 PER CENT OFFSET, PSI							
18 000 psi, min	22 100	22 000	22 300		22 600	22 800	22 100
	21 700	21 800	22 600	22 900	22 200	22 500	22 700
	22 800	22 200	22 300	23 400	23 400	21 700	23 400
	21 600	21 000	22 300	23 000	22 400	22 800	23 000
		21 300	22 400	23 600	21 900	23 100	21 900
				22 400			22 800
Average	22 100	21 700	22 400	23 100	22 500	22 600	22 700
TENSILE STRENGTH, PSI							
28 000 psi, min	39 800	35 200	39 600	40 500	38 400	40 200	33 000
	39 000	38 200	38 100	38 700	31 700	38 100	39 900
	37 500	38 300	39 900	33 200	40 600	39 600	40 700
	39 400	31 800	40 200	39 000	35 800	39 100	38 800
	39 200	34 400	39 800	39 400	30 900	33 800	34 100
	38 100	37 600		38 100		38 200	39 000
Average	38 800	35 900	39 500	38 200	35 500	38 200	37 600
ELONGATION IN 2 IN., PER CENT							
7.0 per cent, min	10.0	6.3^a	9.9	9.3	8.6	10.4	4.8^a
	8.7	8.2	8.4	8.8	4.4^a	7.9	10.3
	8.0	8.8	10.5	5.1^a	9.3	9.9	10.2
	9.9	4.8^a	12.1	8.3	6.4^a	9.0	9.0
	9.2	5.5^a	9.0	8.3	4.1^a	4.5^a	5.9^a
	8.3	8.3		8.0		8.6	9.9
Average	9.0	7.0	10.0	8.0	6.6^a	8.4	8.4

[a] Low.

TABLE XX.—DATA ON ALUMINUM ALLOY NO. ZC81B-T5, PERMANENT MOLD.

ASTM Specification Requirements	As Received	6-months Exposure			1-yr Exposure		
		Penn State	New York	Kure Beach	Penn State	New York	Kure Beach
YIELD STRENGTH, 0.2 PER CENT OFFSET, PSI							
22 000 psi, min	27 100	24 000	23 200	27 500	32 500	24 100	24 200
	29 500		25 700	26 000	30 200		23 500
	24 700	24 200	27 000	24 200	25 800	25 800	
	28 500	25 100	28 900	24 500	27 500	27 700	24 100
	24 600	25 400	26 200	25 100	27 000		26 400
		25 200		25 500			25 000
Average	26 800	24 800	26 200	25 500	28 600	25 900	24 600
TENSILE STRENGTH, PSI							
32 000 psi, min	35 700	34 500	33 100	32 900	44 300	34 500	37 000
	39 100	39 600	38 800	34 400	38 500	26 200	33 800
	32 500	36 000	34 500	29 300	33 000	38 100	36 500
	43 300	35 600	41 100	35 200	35 100	37 100	33 100
	33 700	37 000	37 500	30 100	37 100		30 700
	40 900	36 500		37 300			30 600
	36 900						
Average	37 400	36 500	37 000	33 200	37 600	34 000	33 600
ELONGATION IN 2 IN., PER CENT							
4.0 per cent, min	1.6^a	3.5^a	3.5^a	4.1	4.5	2.9^a	3.0^a
	4.6	1.6^a	5.0	4.8	3.9^a	0.4^a	4.8
	1.5^a	4.4	1.7^a	3.8^a	4.0	5.4	4.8
	5.6	4.5	5.2	4.5	4.5	4.3	2.5^a
	3.6^a	4.9	4.7	2.8^a	4.4		2.2^a
	4.8	4.7		5.7			1.3^a
	5.1						
Average	3.8^a	3.9^a	4.0	4.3	4.3	3.3^a	3.1^a

[a] Low.

TABLE XXI.—DATA ON ALUMINUM ALLOY NO. ZG42A-T5, PERMANENT MOLD.

ASTM Specification Requirements	As Received	6-months Exposure			1-yr Exposure		
		Penn State	New York	Kure Beach	Penn State	New York	Kure Beach
		YIELD STRENGTH, 0.2 PER CENT OFFSET, PSI					
25 000 psi, min	39 100	39 500	40 400	39 400	40 500	39 500	40 400
	40 400	39 300	41 100	41 000	40 500	41 000	43 100
	40 400	39 500	39 700	41 200	40 700	41 300	40 900
	39 700	41 000	40 900	40 900	40 400		40 400
	40 800	39 600	39 400	42 100	40 600	41 700	41 200
			40 100	39 600	39 700	40 500	40 900
Average	40 100	39 800	40 300	40 700	40 400	40 800	41 200
		TENSILE STRENGTH, PSI					
42 000 psi, min	45 300	51 700	47 500	49 100	48 500	50 400	47 100
	50 400	50 300	50 400	49 400	50 800	49 700	51 100
	50 200	51 000	48 300	51 300	50 700	51 700	51 200
	49 200	47 500	49 900	48 100	49 800	49 300	47 900
	49 200	49 500	49 500	51 800	50 600	48 300	51 500
	49 800	50 000	49 700	48 400	47 800	50 900	48 800
	49 800						
Average	49 100	50 000	49 200	49 700	49 700	50 000	49 600
		ELONGATION IN 2 IN., PER CENT					
4.0 per cent, min	1.5^a	4.5	2.9^a	3.0^a	2.4^a	3.5^a	1.8^a
	3.0^a	4.7	3.0^a	2.9^a	3.5^a	2.2^a	2.4^a
	3.6^a	4.0	3.4^a	3.1^a	3.8^a	3.5^a	2.5^a
	2.0^a	2.2^a	2.4^a	3.1^a	3.4^a	2.3^a	1.6^a
	2.3^a	2.9^a	3.3^a	4.0	3.3^a	1.9^a	2.8^a
	3.4^a	3.8^a	2.6^a	3.0^a	3.0^a	3.4^a	1.8^a
	2.5^a						
Average	2.6^a	3.7^a	2.9^a	3.2^a	3.2^a	2.8^a	2.2^a

[a] Low.

TABLE XXII.—DATA ON MAGNESIUM ALLOY NO. AZ63A-T4, SAND CASTING.

ASTM Specification Requirements	As Received	6-months Exposure			1-yr Exposure		
		Penn State	New York	Kure Beach	Penn State	New York	Kure Beach
		YIELD STRENGTH, 0.2 PER CENT OFFSET, PSI					
	15 900	15 900	15 400	16 300	15 500	15 000	16 100
	15 900	16 200	14 800	16 300		15 700	15 800
	15 200	15 400	14 100		16 300	15 600	
	15 900	16 100	15 000	16 400	16 200	16 700	16 400
	16 300	16 200	15 200	13 400	15 200	16 100	15 200
		16 000	14 200	15 200	15 500		15 300
Average	15 800	16 000	14 800	15 500	15 700	15 800	15 800
		TENSILE STRENGTH, PSI					
34 000 psi, min	40 400	41 000	41 100	40 400	36 100	39 600	40 600
	40 000	39 600	39 700	40 400	39 900	39 200	39 100
	42 500	40 100	40 600	41 700	41 300	40 000	40 700
	42 500	41 600	41 500	40 700	41 400	41 200	40 000
	41 300	40 700	41 400	40 900	36 000	41 700	39 900
	40 000	40 100	39 600	40 200	40 200		40 000
	40 600						
Average	41 000	40 500	40 700	40 700	39 200	40 300	40 100
		ELONGATION IN 2 IN., PER CENT					
7.0 per cent, min	14.1	15.4	16.1	16.4	15.7	12.2	15.3
	13.2	14.8	14.6	14.6	15.5	13.7	11.5
	17.2	15.4	13.9	15.2	15.5	14.2	14.8
	16.5	16.6	16.0	13.8	15.6	16.8	12.3
	15.4	15.0	16.1	14.7	14.4	16.2	14.8
	14.2	13.4	15.0	14.2	15.5		14.4
	15.8						
Average	15.2	15.1	15.3	14.8	15.4	14.6	13.9

NOTE.—All specifications on magnesium alloy sand castings include Table II of ASTM Specifications B 80 - 54 T, 1954 Supplement to Book of ASTM Standards, Part 2.

TABLE XXIII.—DATA ON MAGNESIUM ALLOY NO. AZ91C-F, SAND CASTING.

ASTM Specification Requirements	As Received	6-months Exposure			1-yr Exposure		
		Penn State	New York	Kure Beach	Penn State	New York	Kure Beach
YIELD STRENGTH, 0.2 PER CENT OFFSET, PSI							
	15 800	18 500	12 900	18 200	18 900		16 200
	16 400	17 900	14 500	18 000	19 100	16 400	16 600
	16 700	18 100	14 100	17 000	19 100	15 800	17 000
	15 200	18 600	15 400	19 200	18 500	18 100	18 500
	16 700	19 300	14 400	17 600	18 600	17 000	18 100
			14 800	18 400	17 700		16 400
Average	16 200	18 500	14 400	18 100	18 700	16 800	17 100
TENSILE STRENGTH, PSI							
18 000 psi, min	25 300	26 200	20 300	26 400	26 800	24 900	23 800
	26 600	24 600	23 900	26 700	26 500	24 100	23 600
	26 200	25 200	24 300	24 900	26 000	23 800	24 300
	24 200	25 800	25 400	26 300	25 200	24 500	25 900
	26 100	26 200	24 100	25 200	25 800	24 900	25 800
	24 400	25 400	25 400	26 100	24 700		24 600
	26 400						
Average	25 600	25 600	23 900	25 900	25 800	24 400	24 700
ELONGATION IN 2 IN., PER CENT							
	2.6	3.2	1.7	3.2	2.8	2.6	1.8
	3.1	3.0	2.1	2.9	3.1	2.3	1.8
	3.0	2.7	2.0	3.4	2.8	2.8	1.7
	2.8	2.8	2.6	3.4	2.9	2.1	1.9
	2.6	2.8	2.0	3.5	3.3	3.2	1.7
	2.6	3.0	3.0	2.8	2.6		1.8
	3.0						
Average	2.8	2.9	2.2	3.2	2.9	2.6	1.8

TABLE XXIV.—DATA ON MAGNESIUM ALLOY NO. AZ92A-T6, SAND CASTING.

ASTM Specification Requirements	As Received	6-months Exposure			1-yr Exposure		
		Penn State	New York	Kure Beach	Penn State	New York	Kure Beach
YIELD STRENGTH, 0.2 PER CENT OFFSET, PSI							
18 000 psi, min	20 900	21 800	20 200	21 400	19 900	21 700	24 500
	19 000	21 900	17 900[a]	23 000	21 500	21 800	22 900
	18 600	22 800	19 000	24 700	20 000		25 000
	21 400		19 900	22 500	22 600		24 600
	21 800	22 500	19 800	21 600	20 900		23 200
		22 400	19 500		21 000		23 000
Average	20 300	22 300	19 400	22 600	21 000	21 800	23 800
TENSILE STRENGTH, PSI							
34 000 psi, min	41 400	42 500	40 000	41 300	38 800	40 600	41 700
	37 600	41 000	41 400	40 400	40 100	40 900	38 400
	39 300	37 800	41 600	38 800	42 000	39 200	38 200
	41 800	41 800	34 800	40 500	40 400	39 900	39 700
	40 400	41 700	39 800	38 800	41 600	38 700	40 200
	40 300	40 900	37 800	40 600	42 300		41 400
	41 200						
Average	40 300	41 000	39 200	40 100	40 900	39 900	39 900
ELONGATION IN 2 IN., PER CENT							
1.0 per cent, min	4.5	4.2	3.8	4.2	3.0	3.6	3.7
	2.6	4.6	3.5	3.3	3.8	4.4	3.3
	3.2	3.1	4.2	2.3	5.3	3.6	1.8
	4.8	5.2	1.8	3.6	3.5	3.4	2.7
	3.2	5.2	3.2	3.5	3.8	4.1	3.2
	4.0	4.9	2.2	3.7	4.1		3.4
	4.8						
Average	3.9	4.5	3.1	3.4	3.9	3.9	3.3

[a] Low.

TABLE XXV.—DATA ON MAGNESIUM ALLOY NO. EK30A-F, SAND CASTING.

ASTM Specification Requirements	As Received	6-months Exposure			1-yr Exposure		
		Penn State	New York	Kure Beach	Penn State	New York	Kure Beach
			YIELD STRENGTH, 0.2 PER CENT OFFSET, PSI				
	12 900	13 900	13 600	12 400	13 900	11 500	12 800
	12 800	12 900	12 300	13 800	13 300	12 100	13 100
	12 700	12 900	13 100	12 700	13 700	11 800	13 600
	12 400	14 000	13 000	13 000	12 800	12 400	12 500
	12 400	14 000	13 000	12 000	13 100	12 500	13 300
			13 100	14 600	13 900	12 200	12 700
Average	12 600	13 500	13 000	13 100	13 500	12 100	13 000
			TENSILE STRENGTH, PSI				
	19 200	19 400	17 900	17 400	18 500	16 700	17 500
	19 600	18 300	16 600	18 700	18 100	17 700	17 700
	19 800	17 600	17 200	17 200	20 200	17 400	17 800
	19 600	19 800	17 200	17 200	17 400	17 600	16 700
	19 300	19 900	17 100	15 700	19 300	18 200	17 700
	19 000	19 900	16 900	19 200	18 900	17 700	16 300
	19 200						
Average	19 400	19 200	17 200	17 600	18 700	17 600	17 300
			ELONGATION IN 2 IN., PER CENT				
	2.3	3.3	1.9	2.3	3.2	2.4	2.0
	3.2	2.1	1.7	2.5	2.5	1.8	1.1
	3.3	2.0	1.6	2.3	3.3	2.5	1.9
	2.2	3.1	2.1	2.7	2.7	2.6	2.0
	3.0	3.1	1.9	1.6	2.8	2.5	2.1
	2.8	2.7	1.9	2.5	2.7	2.5	1.7
	2.9						
Average	2.8	2.7	1.9	2.3	2.9	2.4	1.8

TABLE XXVI.—DATA ON MAGNESIUM ALLOY NO. EK30A-T6, SAND CASTING.

ASTM Specification Requirements	As Received	6-months Exposure			1-yr Exposure		
		Penn State	New York	Kure Beach	Penn State	New York	Kure Beach
			YIELD STRENGTH, 0.2 PER CENT OFFSET, PSI				
14 000 psi, min	16 400	17 300		16 700			
	16 800	16 600		16 800			
	16 800	16 800		17 400			
	16 400	16 300		16 700			
	17 100	16 100		17 600			
	16 600	17 200		17 500			
	15 400						
Average	16 500	16 700		17 100			
			TENSILE STRENGTH, PSI				
18 000 psi, min	23 400	22 300		24 300			
	24 500	22 300		23 600			
	24 300	22 800		24 700			
	23 700	23 000		24 300			
	24 300	23 400		25 000			
	22 500	20 000		24 000			
	22 100						
Average	23 500	22 300		24 300			
			ELONGATION IN 2 IN., PER CENT				
1.0 per cent, min	3.0	1.5		3.3			
	4.5	2.4		2.2			
	3.5	2.5		3.1			
	3.6	2.9		3.0			
	3.5	2.6		3.1			
	3.5	1.2		3.4			
	2.6						
Average	3.3	2.2		3.0			

TABLE XXVII.—DATA ON MAGNESIUM ALLOY NO. AZ91C-T6, SAND CASTING.

ASTM Specification Requirements	As Received	6-months Exposure			1-yr Exposure		
		Penn State	New York	Kure Beach	Penn State	New York	Kure Beach
YIELD STRENGTH, 0.2 PER CENT OFFSET, PSI							
16 000 psi, min	22 300	20 800		23 300			
	21 300	20 300		22 900			
	21 900	21 500		21 100			
	21 300	20 600		23 200			
	21 700	20 000		21 000			
	21 700	22 000		20 100			
Average	21 700	20 900		21 900			
TENSILE STRENGTH, PSI							
34 000 psi, min	37 000	39 500		38 400			
	40 500	36 100		40 300			
	39 700	41 200		40 400			
	42 300	35 100		40 900			
	41 100	41 000		40 400			
	39 600	39 000		35 900			
Average	40 000	38 700		39 400			
ELONGATION IN 2 IN., PER CENT							
3.0 per cent, min	3.0	5.3		3.4			
	3.7	4.6		3.9			
	4.1	5.3		4.6			
	5.8	3.2		4.6			
	5.2	5.6		5.0			
	4.1	4.8		3.6			
Average	4.3	4.8		4.2			

TABLE XXVIII.—DATA ON MAGNESIUM ALLOY NO. EZ33A-T5, SAND CASTING.

ASTM Specification Requirements	As Received	6-months Exposure			1-yr Exposure		
		Penn State	New York	Kure Beach	Penn State	New York	Kure Beach
YIELD STRENGTH, 0.2 PER CENT OFFSET, PSI							
14 000 psi, min	15 800	13 900[a]		13 100[a]			
	15 900	13 400[a]		13 300[a]			
	15 700	13 800[a]		13 300[a]			
	15 100	13 200[a]		13 100[a]			
	15 300	13 500[a]		13 600[a]			
	15 400	13 700[a]		14 000			
	15 600						
Average	15 500	13 600[a]		13 400[a]			
TENSILE STRENGTH, PSI							
18 000 psi, min	21 400	19 300		18 700			
	19 700	16 700[a]		17 300[a]			
	22 200	17 700[a]		18 400			
	18 400	18 700		18 400			
	20 700	17 400[a]		16 400[a]			
	22 000	18 400		16 000[a]			
	22 700						
Average	21 000	18 000		17 500[a]			
ELONGATION IN 2 IN., PER CENT							
1.0 per cent, min	2.9	2.0		1.9			
	1.6	1.2		1.6			
	3.0	1.6		1.2			
	1.3	2.2		1.6			
	2.7	1.8		1.3			
	3.2	2.0		0.8[a]			
	3.7						
Average	2.6	1.8		1.4			

[a] Low.

REPORT OF COMMITTEE B-8

ON

ELECTRODEPOSITED METALLIC COATINGS*

Committee B-8 on Electrodeposited Metallic Coatings held two meetings during the year: one on October 15, 1953, at ASTM Headquarters in Philadelphia, Pa., and one in Washington, D. C., on February 5, 1954.

The membership of the committee now consists of 114 members, of whom 41 are classified as producer, 16 as consumer, 57 as general interest, and 10 as consulting members.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, C. H. Sample.

Vice-Chairman, K. M. Huston.

Secretary, R. B. Saltonstall.

Advisory Committee Members-at-Large, Herb Head and R. D. Miller.

REVISION OF STANDARDS, IMMEDIATE ADOPTION

The committee recommends for immediate adoption revisions as indicated in the following two standards, and accordingly asks for the necessary nine-tenths affirmative vote at the Annual Meeting in order that the revisions may be referred to letter ballot of the Society:

Recommended Practice for Preparation of High-Carbon Steel for Electroplating (**B 242 – 53**).[1]

Section 5(f).—Change title to "Anodic Acid Etching." In line 2 of the first paragraph change the word "treatment" to "etch." In line 5 of the second paragraph, change the word "treatment" to "etching." In the third paragraph, delete the last two sentences.

Add the following new Paragraph 5(*g*):

(*g*) Electropolishing. — Electropolishing is used to remove highly stressed metal and metal debris from the surface of cold-worked steel, thereby improving the bond strength and corrosion resistance of electroplated coatings. It accomplishes this function without the tendency to form smut, which may result from anodic etching. Since it does not etch the steel, it is preferred by some electroplaters to anodic etching for preparing steel surfaces for decorative plating. Proprietary mixtures of phosphoric and sulfuric acids[a] for electropolishing are of special interest in view of their ability to remove smut from cast iron surfaces. The addition of chromic acid to sulfuric-phosphoric acid mixtures[b] further provides a surface passivation characteristic that is beneficial for preventing rusting during transfer or during temporary storage of steel prior to plating.

An activating treatment after electropolishing may be beneficial to subsequent plating. An example of a suitable activating treatment is anodic cleaning followed by acid dipping. Electropolishing can be used in addition to or instead of anodic etching.

Electropolishing of fine-grained steel provides a uniform, smooth finish. Coarse-grained structure (No. 6 or coarser) results in lesser smoothness. In either case, however, a word of caution is interjected that any seams, voids, stringers, and other surface defects may be damaging to the appearance of the electroplated coating. Yet, the removal of sharp edges or scratches and the removal of nonmetallic inclusions in seams and stringers may reduce the harmful effect of these defects on the corrosion resistance of the electroplated steel.

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13–18, 1954.

[1] 1953 Supplement to Book of ASTM Standards, Part 2.

[a] U. S. Patent 2,334,699.

[b] U. S. Patents 2,366,712 and 2,338,321.

Standard Specifications for Electrodeposited Coatings of Nickel and Chromium on Zinc and Zinc-Base Alloys (**B 142–53**).[1]

Section 4(a).—Change to read as follows:

4. (*a*) The periods of continuous exposure to the salt-spray test (Section 9) which coatings shall withstand without showing appreciable corrosion on significant surfaces shall be agreed upon between the manufacturer and the purchaser.[a]

---

[a] Based on the work of Subcommittee III which showed observed failures to obtain reproducible results on replicate panels in different salt-spray cabinets operated in accordance with ASTM Method B 117, the periods of continuous exposure to the salt spray are not specified herein.

REVISION OF TENTATIVES

The committee recommends that the following tentative specifications be revised as indicated and continued as tentative:

Tentative Specifications for Electrodeposited Coatings of Nickel and Chromium on Steel (**A 166 – 53 T**):[1]

Section 4. Continuity of Coatings.—Change Paragraph (*a*) to read as folows:

4. (*a*) The periods of continuous exposure to the salt-spray test (Section 9) which coatings shall withstand without showing appreciable corrosion on significant surfaces shall be agreed upon between the manufacturer and the purchaser.[a]

---

[a] Based on the work of Subcommittee III which showed observed failures to obtain reproducible results on replicate panels in different salt-spray cabinets operated in accordance with ASTM Method B 117, the periods of continuous exposure to the salt spray are not specified herein.

Tentative Specifications for Electrodeposited Coatings of Lead on Steel (**B 200 – 53 T**):[1]

Section 3(a).—Add the following note:

NOTE.—For lead coating thicknesses of 0.00025 in. (6.4 μ) or greater, the copper undercoat improves the corrosion protection offered by the coating to the steel basis metal.

Section 4. Continuity of Coatings.—Change Paragraph (*a*) to read as follows:

4. (*a*) The periods of continuous exposure to the salt-spray test (Section 9) which coatings shall withstand without showing appreciable corrosion on significant surfaces shall be agreed upon between the manufacturer and the purchaser.[a]

---

[a] Based on the work of Subcommittee III which showed observed failures to obtain reproducible results on replicate panels in different salt-spray cabinets operated in accordance with ASTM Method B 117, the periods of continuous exposure to the salt spray are not specified herein.

Tentative Specifications for Chromate Finishes on Electrodeposited Zinc, Hot-Dipped Galvanized, and Zinc Die-Cast Surfaces (**B 201 – 49 T**):[2]

Section 3. Protective Value of Coatings. Change Paragraph (*a*) to read as follows:

3. (*a*) The periods of continuous exposure to the salt-spray test (Section 6 (*c*)) which coatings shall withstand without showing appreciable corrosion on significant surfaces as prepared according to Section 6 (*a*) and (*b*) shall be agreed upon between the purchaser and the manufacturer.[a]

---

[a] Based on the work of Subcommittee III which showed observed failures to obtain reproducible results on replicate panels in different salt-spray cabinets operated in accordance with ASTM Method B 117, the periods of continuous exposure to the salt spray are not specified herein.

ADOPTION OF TENTATIVE AS STANDARD

Committee B-8 recommends jointly with Committee A-5 on Corrosion of Iron and Steel that the Tentative Methods of Test for Local Thickness of Electrodeposited Coatings (**A 219 – 51 T**)[2] be approved for reference to letter ballot of the Society for adoption as standard without revision.

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[3]

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[2] 1952 Book of ASTM Standards, Part 2.

[3] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

Activities of Subcommittees

Subcommittee I on Papers, Specifications, and Definitions (F. Ogburn, chairman).—A. Korbelak has been appointed chairman of Section B on Definitions, and the compilation of a glossary of terms used in electrodeposition and allied fields is being continued.

A symposium committee under the chairmanship of G. Lux is planning a symposium for Committee Week in 1955 or 1956.

Two task groups have been appointed to investigate the desirability and feasibility of writing specifications for materials used in plating, such as anodes and chemicals, and plated coatings other than those covered by existing ASTM specifications.

A number of the recommendations affecting standards referred to previously in the report were prepared by this subcommittee.

Subcommittee II on Performance Tests (W. L. Pinner, chairman).—Steel panels plated with copper-nickel-chromium and nickel-chromium identified as "Program 3 Panels" were exposed at New York, Kure Beach, and Detroit in May and June, 1953 (see 1953 report).[4] Early inspection data indicate unexpectedly early failure in some cases. Regular inspections are being continued.

Inspections of lead-coated steel panels are being continued, and a report covering the most recent exposure data will be forthcoming during the ensuing year.

R. E. Harr has been appointed chairman of Section C on Performance of Supplementary Coatings. Conversion coatings on zinc-plated steel panels were exposed at New York and Kure Beach in August, 1953. Visual inspection and rating of these coatings is being supplemented with colored photographs.

Experience with the new rating method, in which various weight factors are assigned to different defects, has been encouraging.

Subcommittee III on Conformance Tests (R. F. Ledford, chairman).—Work on measuring plate thickness by different methods is progressing slowly.

The report of Section B on Porosity Tests is appended[5] to this report. As a result of this report, Subcommittee III recommended to Subcommittee I revisions of certain standards and tentatives in which salt-spray hours are specified.

B. C. Case has been appointed chairman of Section E on Adhesion Tests.

Subcommittee IV on Electroplating Practice (Max Frager, chairman).—Previously organized sections of this subcommittee are continuing work on their assignments.

The task group had been appointed to investigate the desirability and feasibility of preparing a recommended practice on cleaning of metals prior to electroplating, and as a result of its recommendation Section K under the chairmanship of Samuel Spring has been formed and charged with the drafting of the practice. Review of the cleaning cycles in existing recommended practices will be an early part of this work.

Subcommittee V on Supplementary Treatments for Electrodeposited Metallic Coatings (Marc Darrin, chairman).—Section B on Accelerated Tests under the chairmanship of A. Mendizza reported that salt spray tests on chromated zinc plate could not be reproduced by different laboratories. As a result, Subcommittee V recommended to Subcommittee I revision of Tentative Specifications for Chromate Finishes on Electrodeposited Zinc, Hot-Dipped Galvanized, and Zinc Die-Cast Surfaces (B 201 – 49 T). Spot tests on chromate coatings have been disappointing, and other accelerated tests are being investigated.

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[4] *Proceedings*, Am. Soc. Testing Mats., Vol. 53, p. 251 (1953).

[5] See p. 299.

Section D on Cadmium Treatments (L. Gilbert, chairman) reported completion of 800 chromate-treated cadmium plated panels which are to be exposed in the near future.

Section E on Phosphate Treatments has submitted a detailed report. Several hundred phosphate-coated panels have been sent to Naval Research Laboratories for special tests.

At the suggestion of its chairman, E. Roehl, Section G on Surface Treatments for Lead has been dissolved because interest in the subject was lacking.

Other sections reported progress on their assignments.

This report has been submitted to letter ballot of the committee, which consists of 114 voting members; 82 members returned their ballots, of whom 72 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

C. H. SAMPLE,
Chairman.

R. B. SALTONSTALL,
Secretary.

APPENDIX

REPORT OF SECTION B ON POROSITY TESTS OF SUBCOMMITTEE III ON CONFORMANCE TESTS

Salt Spray Tests of Copper-Nickel-Chromium Deposits

The salt spray test per ASTM Tentative Method B 117[1] is employed as an acceptance test in ASTM Tentative Specification A 166[2] covering copper-nickel-chromium coatings on steel. Doubt has been expressed by a significant number of users of this test as to its validity in predicting quality of these finishes. Section B of Subcommittee III of ASTM Committee B-8 has been charged with the task of conducting an investigation to ascertain to what degree the salt spray test as currently performed can be relied upon in predicting quality of the finishes covered by Specification A 166. Specifically, the principal objectives of the proposed investigation were (1) to determine the relationship between salt spray resistance and thickness of coating, and (2) to determine the degree of reproducibility of salt spray test results for coatings prepared to the same thickness requirements by several producers and tested by several testers whose boxes would conform to B 117.

A program was therefore drawn up, designed to furnish answers to these questions.

Identical sets of 16 specimens were prepared by six platers for each of six coatings. The coatings, on two types of steel, are outlined below:

On NAX Steel:

Coating A—0.0015-in. nickel
Coating B—Copper flash + 0.0015-in. nickel
Coating C—0.0009-in. copper + 0.0006-in. nickel
Coating D—0.00125-in. nickel

On 1010 Steel:

Coating E—0.00125-in. nickel
Coating F—0.00075-in. nickel

A final flash coating of chromium was applied on all panels. The various finishing systems were prepared in quadruplicate. No restrictions were imposed on the plating laboratories except that the samples should be prepared in accordance with best commercial practices, and that efforts should be made to plate uniform coatings as closely to the desired thickness as possible. Either bright nickel or dull nickel, buffed, was permissible, provided the resulting finish was comparable to a good commercial automobile bumper finish.

The size of the test panels was 4 by 6 by $\frac{1}{8}$ in. All panels contained a semispherical deformation in the center produced by an Olsen cup. This deformation was roughly 1 in. in diameter and $\frac{1}{2}$ in. in height and was designed to simulate forming operations. The purpose of this deformation was to ascertain whether the salt spray resistance of the finish was measurably affected by stresses set up in the basis metal.

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[1] Tentative Method of Salt Spray (Fog) Testing (B 117 - 49 T), 1952 Book of ASTM Standards, Part 2, p. 1037.

[2] Tentative Specifications for Electrodeposited Coatings of Nickel and Chromium on Steel (A 166 - 45 T), 1952 Book of ASTM Standards, Part 2, p. 973.

The grand total number of test panels required for this program was 576. Actually, only 544 panels were prepared, inasmuch as one plater supplied only four types of coatings, as noted below.

Prior to plating all test panels were strip-polished using various grit sizes. The NAX steel panels received a final pass with size 240 grit and the 1010 steel with size 180 grit, greased.

The condensed plating schedule used by the various laboratories is shown below:

Plater 1

No plating schedule available. This plater was not set up for copper plating and consequently produced only sets A, D, E, and F.

Plater 2

Cathodic and anodic alkaline clean, followed by acid dip.

Cyanide copper strike, where flash coating only was required.

Cyanide copper plus acid copper, buffed where heavy copper was required.

Proprietary bright nickel.

Conventional chromium.

Plater 3

Degreased with trichloroethylene, anodic alkaline clean, followed by acid dip.

Cyanide copper for flash and heavy plate.

Watts nickel, buffed.

Conventional chromium.

Plater 4

Degreased with trichloroethylene, anodic clean in proprietary cleaner and acid dip.

Repeat anodic clean.

Cathodic acid pickle.

Cyanide copper strike for flash coatings.

Cyanide copper plus proprietary high-speed copper for heavy plate.

Acid nickel strike prior to nickel plating only.

Proprietary chromium plate.

Plater 5

Degreased with trichloroethylene.

Electrolytic clean in proprietary cleaner.

Scrub with brush.

Acid pickle.

Cyanide copper for flash and heavy deposits.

Proprietary bright nickel.

Conventional chromium.

Plater 6

Anodic clean with proprietary cleaner.

Brush.

Anodic acid etch.

Proprietary semibright nickel.

Buff.

Cathodic clean in proprietary solution.

Acid dip.

Conventional chromium.

The plated panels prepared for the salt spray tests were randomly mixed up and distributed to four laboratories[3] for determinations of thicknesses of coating. Thickness measurements were made by non-destructive methods (magne-gage or similar) of all the nickel coatings. Two measuring laboratories were also able to determine the thickness of the copper coatings by means of a composite gage. In a few instances microsectioning methods and determinations by stripping were made for check purposes. The thickness measurements were made at four spots on each panel—on the flat areas, in two spots roughly diagonally across the panel, and at the top and at the bottom of the cup impression. The results of these tests show that in the majority of cases the thickness at the top of the impression was excessively greater and that at the bottom considerably smaller than the two readings on the flat portion of the panels. The thickness determinations by microsectioning revealed that the reported values do not very closely correspond to the requested thicknesses. Of the two laboratories who measured both nickel and copper thicknesses, one reported "flash" copper coatings ranging from 0.00013 to 0.00036 in., with the majority of values around 0.00025 in.

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[3] A fifth laboratory, Laboratory e, made magne-gage measurements as well as chemical analysis and microsectioning tests on the extra panels.

Following the thickness determinations, the panels were sent to four testing laboratories for salt spray testing in accordance with a predetermined random schedule. Essentially, this schedule consisted in grouping all panels into sets of 16 panels having the same type of coating applied by one plating laboratory. Inasmuch as each of five laboratories prepared 16 panels of each of the six types of coatings and one laboratory (plater 1) plated 16 panels of each of only four types of coatings (no copper coatings), there resulted a total of 34 sets. The assignment of specimens was then made following the scheme outlined below.

TABLE I.—DISTRIBUTION OF PANELS IN TEST BOXES.

Position	Laboratory I		Laboratory II		Laboratory III		Laboratory IV	
	Run 1 Run 3	Run 2 Run 4	Run 1 Run 3	Run 2 Run 4	Run 1 Run 3	Run 2 Run 4	Run 1 Run 3	Run 2 Run 4
1....	E-4	A-1	B-3	D-1	F-2	C-3	E-2	D-6
2....	A-4	F-2	F-2	F-3	A-3	A-2	D-4	E-5
3....	E 1	C-2	D-2	F-1	D-1	E-2	B-5	D-3
4....	F-3	C-5	A-5	D-4	...	F-6	F-4	C-3
5....	A-6	E-4	D-5	F-5	B-2	A-5	D-1	D-2
6....	...	C-4	F-6	...	E-5	D-4	C-2	B-5
7....	C-4	F-4	E-5	E-6	D-5	E-5	B-4	F-6
8....	B-5	E-1	A-2	C-4	A-1	D-1	...	C-2
9....	C-2	A-4	F-4	A-4	A-6	C-2	E-5	D-1
10....	A-2	B-5	D-1	C-2	C-2	B-3	E-4	C-5
11....	C-3	F-6	E-6	D-2	E-3	C-5	A-4	A-5
12....	B-3	...	...	E-4	B-5	...	B-2	E-4
13....	F-5	D-3	B-2	...	C-3	E-6	D-6	D-4
14....	D-5	A-3	E-1	D-6	E-6	F-2	A-3	F-4
15....	F-4	D-4	E-4	B-2	B-4	B-5	A-1	F-2
16....	A-5	E-3	C-2	A-5	D-4	D-6	F-3	A-3
17....	D-2	B-2	F-5	D-3	F-3	A-1	B-3	D-5
18....	F-2	E-2	...	A-6	E-1	...	F-5	A-2
19....	E-5	B-4	A-6	B-3	B-3	F-3	F-6	B-2
20....	A-1	A-5	F-1	D-5	A-2	F-1	D-2	F-1
21....	E-6	F-3	C-4	A-3	F-6	D-3	E-6	B-3
22....	F-6	D-6	A-1	A-2	D-3	D-5	A-6	C-4
23....	D-3	F-5	A-3	C-3	E-2	F-4	C-3	A-4
24....	F-1	D-2	C-3	E-1	C-5	B-2	C-5	E-3
25....	D-1	D-1	E-3	B-5	E-4	E-3	D-5	B-4
26....	B-4	B-3	E-2	F-2	F-5	E-4	...	...
27....	D-6	...	F-3	E-3	...	A-4	A-2	A-1
28....	...	A-6	C-5	C-5	F-4	D-2	E-3	F-5
29....	D-4	F-1	D-6	F-6	D-6	E-1	E-1	E-6
30....	C-5	D-5	D-3	F-4	F-1	A-6	F-2	A-6
31....	A-3	E-6	B-5	E-5	D-2	F-5	A-5	E-2
32....	E-2	C-3	A-4	A-1	A-5	B-4	F-1	...
33....	B-2	A-2	D-4	B-4	C-4	A-3	D-3	E-1
34....	E-3	E-5	B-4	E-2	A-4	C-4	C-4	F-3

NOTE.—The letter designates the coating and the digit the plater. Thus E-4 under Laboratory I, Run 1, Run 3, represents two panels made by plater 4 with 0.00125-in. nickel and tested by Laboratory I in position 1 in the first and in the third runs, respectively.

Each set of 16 panels was randomly partitioned into four groups of four panels. One group was assigned to each of the four testing laboratories.

Each laboratory numbered 34 positions in its salt spray chamber; only these positions were used in the tests.

Each laboratory received 4 × 34 (or 136) panels and, hence, made four test runs. The assignment of the sets to individual positions in the test boxes was made in accordance with the predetermined random schedule shown in Table I.

Each laboratory thus had four panels of each set and assigned these four panels to four runs at random.

It was hoped that the following questions would be answered by this study:

1. How reproducible are the results on the same type of finish from:

(*a*) The same laboratory in the same position.

(*b*) The same laboratory in different positions.

(*c*) Different laboratories.

2. Do the laboratories differ in plating panels of the same coating type.

3. How do the six types of coatings differ among themselves.

The salt spray tests were then run by the four testing laboratories in accordance with this schedule. Each laboratory endeavored to maintain the conditions within each box within the limits prescribed by B 117.

The results obtained from these tests are summarized in Tables II to VII. In supplementary Tables IIA to VIIA are recorded the corresponding thickness values of the test panels. As indicated earlier in this report, the measurements at the top and the bottom of the indentation were erratic and, consequently, they have not been reported here. The values shown are those obtained on the flat portion of the panels.

TABLE II.—SALT SPRAY TEST ON 0.0015-IN. NICKEL ON NAX STEEL (COATING A) SHOWING NUMBER OF RUST SPOTS ON FLAT AREA OF 4 BY 6-IN. PANEL.

Plater	Time, hr	Laboratory I				Laboratory II				Laboratory III				Laboratory IV			
		Run 1	Run 3	Run 2	Run 4	Run 1	Run 3	Run 2	Run 4	Run 1	Run 3	Run 2	Run 4	Run 1	Run 3	Run 2	Run 4
No. 1............	24	...	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0
	96	...	5	4	1	0	1*	0	1	2*	2*	1*	0	3*	1	2*	3*
	200	...	...	...	...	0	1*	0	1	3*	2*	1*	1	3* (400)	3*	2*	3*
No. 2............	24	2	3	...	0	0	0	0	0	1	3	2	0	1	0	0	4
	96	2	17	...	1	0	0	0	0	1, 2*	4*	3*	0	2*	1, 1*	1, 1*	5, 4*
	200	...	...	...	...	0	0	0	0	1, 2*	...	...	1*	4* (120)	...	...	4, 3*
No. 3............	24	1	0	2	0	0	0	0	0	0	0	0	0	0	...	0	0
	96	>25, S*	3	10	7	0	0	0	1	1*	0	1, 1*	1*	0	...	2*	9*
	200	...	...	...	...	0	0	0	2, 1*	2, 12* (400)	3* (500)	1, 2* (500)	3* (500)	1* (400)	...	2*	9*
No. 4............	24	...	4	3	2	3, 4*	60	7	50	1	0	2	2	1	4	2, 1*	4*
	96	...	20	20	25, S*	2**	60, 7*	7, 3*	60	3*	2, 3*	2*	6, 10*	4, 3*	12, 5*	3, 3*	1, 6*
	200	...	...	...	...	1, 2*	60, 9*	7, 2**	60	...	...	...	...	1, 5* (120)	...	...	...
No. 5............	24	12, S*	16	5	12	1	0	0	0	0	1, 1*	8, 3*	3	0	0	...	0
	96	>25, S*	18, S*	6, 1*	14, 8*	5, 1*	5	19	3	2, 5*	10, 12*	5, 12*	4, 11*	0	1*	...	5, 1*
	200	...	...	...	...	6, 2*	13	15, 2*	5	6, 14*	...	2, 18*	4, 22*	0 (400)	1*	...	13, 1*
No. 6............	24	0	1	1	...	0	0	0	0	1	0	0	0	0	0	0	0
	96	12, S*	25	20	...	0	0	0	0	2	7, 3*	3*	0	1*	1*	0	1*
	200	...	...	...	...	1	0	0	0	2	16, 11*	4*	3, 2*	1* (400)	2*	2*	1, 2*

NOTES.—* and ** denote spots 1/16 in. in diameter or larger.
Figures in parentheses denote hours test was actually run.
S* = more than one spot 1/16 in. in diameter or larger but exact number of spots not recorded.

TABLE IIA.—THICKNESS IN MILS (0.001 IN.) WHEN NOMINAL THICKNESS = 0.0015 IN. Ni (A).
Average of two readings on flat surface—magne-gage method.
Panels in same order as in Table II.

Plater No. 1	Panel	. . . (a) . . .	N174 0.80	N177 1.20	N176 1.17	N198 (b) 1.42	N186 1.49	N189 1.47	N191 1.21	N217 (c) 1.32	N206 1.12	N205 1.25	N208 1.50	N199 (d) 1.50	N203 1.35	N201 1.43	N204 1.40	N167 (e) 1.36 1.18 (1)
Plater No. 2	Panel	N90 (b) 1.58	N84 1.42	. . . . . .	N88 1.55	N93 (b) 1.57	N91 1.49	N92 1.57	N94 1.60	N102 (c) 1.79	N99 1.77	N100 1.60	N101 1.62	N95 (d) 1.60	N97 1.60	N96 1.54	N98 1.59	N86 (e) 1.50 1.15 (1)
Plater No. 3	Panel	N336 (a) 1.66	N334 1.92	N333 >2.40	N335 >2.60	N340 (d) 1.75	N338 1.71	N337 1.66	N339 1.68	N348 (c) 1.9	N345 1.74	N347 1.77	N346 1.74	N341 (c) 1.78	. . . . . .	N342 1.55	N344 1.64	N343 (e) 1.69 1.65 (1)
Plater No. 4	Panel	. . . (a) . . .	N418 1.82	N417 1.94	N419 1.75	N420 (b) 1.80	N422 1.68	N423 1.74	N421 1.74	N430 (c) 1.68	N432 1.76	N431 1.83	N433 1.83	N426 (c) 1.74	N424 1.78	N428 1.81	N425 1.88	N416 (e) 1.87 1.39 (1) 1.18 (2)
Plater No. 5	Panel	N254 (a) 2.00	N257 1.97	N255 1.92	N256 1.84	N261 (b) 1.66	N259 1.76	N258 1.62	N260 1.77	N320 (c) 1.92	N317 >2.0	N316 1.95	N319 >2.0	N264 (d) 1.66	N262 1.89	. . . . . .	N265 1.88	N263 (e) 1.75 1.66 (1)
Plater No. 6	Panel	N2 (a) 1.21	N1 1.28	N3 1.29	. . . . . .	N8 (b) 1.46	N5 1.32	N6 1.47	N7 1.36	N16 (c) 1.35	N13 1.25	N15 1.28	N14 1.50	N9 (d) 1.30	N11 1.37	N10 1.33	N12 1.42	N4 (e) 1.61 1.25 (1)

NOTES.—The letters a, b, c, d, and e in parentheses represent laboratories that measured with the magne-gage.
(1) Measured by chemical analysis.
(2) Measured by microsectioning.

TABLE III.—SALT SPRAY TEST ON COPPER FLASH PLUS 0.0015-IN. NICKEL ON NAX STEEL (COATING B) SHOWING NUMBER OF RUST SPOTS ON FLAT AREA OF 4 BY 6-IN. PANEL.

Plater	Time, hr	Laboratory I				Laboratory II				Laboratory III				Laboratory IV			
		Run 1	Run 3	Run 2	Run 4	Run 1	Run 3	Run 2	Run 4	Run 1	Run 3	Run 2	Run 4	Run 1	Run 3	Run 2	Run 4
No. 2	24	2	0	0	3	0	0	. . .	0	0	1	0	0	1	0	0	0
	96	2, 1*	1	0	1, 3*	0	0	. . .	0	0	1, 1*	1	1	1, 3*	3*	1*	4*
	200	. . .	. . .	. . .	. . .	0	0	. . .	1	1* (400)	2* (168)	2, 3*	. . .	2*	3*	3*	1, 7*
No. 3	24	2	0	3	1	0	0	0	0	0	. . .	0	1	0	1	1	0
	96	>25, S*	6	13	~21	0	1	1	1	11*	. . .	1	1*	0	1, 3*	1, 3*	2*
	200	. . .	. . .	. . .	. . .	0	1	1	1	4, 26*	. . .	1*	1*	1*	1, 4*	1, 3*	4, 2*
No. 4	24	1	3	3	6	. . .	2	1	1	0	13, 2*	0	2	0	1	12, 1*	1, 2*
	96	>25, S*	~25	>25	>25, S*	. . .	1, 1*	0	4, 1*	3	17, 18*	3, 5*	10, 2*	2, 3*	1, 1*	23, 3*	1, 3*
	200	. . .	. . .	. . .	. . .	. . .	1, 1*	1	7	. . .	. . .	. . .	. . .	6*	. . .	. . .	5, 4*
No. 5	24	3	2	11	4	0	0	0	0	94, 6*	1	. . .	0	0	0	0	0
	96	>25, S*	18	>25	>25	2	4	0	2	82, 23*	29, 45*	. . .	40, 14*	1*	1	0	1, 6*
	200	. . .	. . .	. . .	. . .	8	5	45 (1)	12	. . .	. . .	. . .	. . .	2*	3, 1*	1*	10*
No. 6	24	3	2	0	2	0	0	0	. . .	5	2, 1*	1	1	0	0	0	1*
	96	18, S*	16	>25	11	0	1	1	. . .	7, 5*	1, 5*	1, 1*	7	1	1*	1	1*
	200	. . .	. . .	. . .	. . .	2	2	1	. . .	3, 31*	4, 11*	1, 1*	11, 3*	3	2, 2*	19, 3* (2)	20, 2* (3)

NOTES.—(1)—168 hr—1 (2)— 96 hr—2
120 hr—4, 1* (3)— 96 hr—1*
120 hr—12, 1*

Other notes as in Table II.

TABLE IIIA.—THICKNESS IN MILS (0.001 IN.) WHEN NOMINAL THICKNESS=COPPER FLASH PLUS 0.0015-IN. NICKEL (COATING B).

Average of two readings on flat area—magne-gage method.
Top reading, nickel; bottom reading, copper.
Panels in same order as in Table III.

Plater No. 2.....	Panel	N103 (b) 1.44 0.16	N105 1.30 0.18	N107 1.41 0.16	N106 1.33 0.15	N110 (b) 1.44 0.16	N108 1.52 0.17	... ...	N111 1.43 0.18	N121 (d) 2.16	N117 1.88	N116 1.89	N120 1.90	N112 (d) 1.77	N114 1.86	N113 1.83	N115 1.90	N109 1.38 (*1*) 0.10		
Plater No. 3.....	Panel	N349 (a) 1.22 0.12	N350 1.20 0.16	N352 0.85 0.27	N351 1.14 0.18	N355 (a) 0.95 0.22	N356 1.00 0.22	N353 0.96 0.21	N354 1.02 0.23	N361 (d) 1.59	... ...	N367 1.61	N362 1.53	N360 (d) 1.61	N358 1.59	N359 1.49	N357 1.54	N363 (e) 1.59	1.58 (*1*) <0.01	1.59 (*2*) <0.02
Plater No. 4.....	Panel	N439 (a) 0.89 0.32	N438 0.81 0.33	N436 0.94 0.28	N437 0.78 0.34	... (a)	N441 1.06 0.32	N443 1.11 0.25	N442 0.91 0.33	N454 (b) 1.24 0.14	N452 1.10 0.20	N451 1.31 0.14	N453 1.21 0.13	N447 (b) 1.61 0.09	N449 1.21 0.13	N448 1.26 0.13	N450 1.32 0.11	N440 1.40 (*1*) 0.02		
Plater No. 5.....	Panel	N250 (a) 1.03 (0.00) (0.28)	N251 0.77 0.21	N253 1.08 0.16	N252 0.72 0.28	N271 (b) 1.18 0.06	N274 1.19 0.13	N269 1.13 0.13	N270 1.19 0.10	N315 (d) 1.24	N280 1.26	... ...	N314 1.36	N276 (b) 1.23 0.06	N278 1.16 0.12	N277 1.36 0.03	N279 1.13 0.06	N281 1.00 (*1*) 0.01		
Plater No. 6.....	Panel	N20 (a) 1.03 0.25	N17 0.78 0.28	N19 0.89 0.27	N18 0.90 0.23	N21 (a) 0.98 0.26	N22 0.98 0.22	N23 0.90 0.26	... ...	N31 (d) 1.46	N30 1.41	N32 1.47	N29 1.44	N25 (b) 1.13 0.12	N27 1.14 0.13	N26 1.19 0.10	N28 1.29 0.07	N24 1.40 (*1*) 0.03		

NOTES.—Laboratory d measured composite nickel and copper as total nickel.
Other notes as in Table IIA.

TABLE IV.—SALT SPRAY TEST ON 0.0009-IN. COPPER PLUS 0.0006-IN. NICKEL ON NAX STEEL (COATING C) SHOWING NUMBER OF RUST SPOTS ON FLAT AREA OF 4 BY 6-IN. PANEL.

Plater	Time, hr	Laboratory I				Laboratory II				Laboratory III				Laboratory IV			
		Run 1	Run 3	Run 2	Run 4	Run 1	Run 3	Run 2	Run 4	Run 1	Run 3	Run 2	Run 4	Run 1	Run 3	Run 2	Run 4
No. 2............	24	∼20, S*	>25	19	∼20	0	0	0	0	0	0	1*	0	0	0	...	2*
	72	>25, S*	>25*	>25, S*	>25, S*	1	0	0	0	1	1*	2, 1*	1	0	4*	...	5*
	200	...	...	...	...	13	0	0	0	2	1*	2, 1*	1, 1* (144)	4* (400)	4*	...	6*
No. 3............	24	3, 1*	0	10	...	0	0	0	0	0	0	0	0	0	0	0	2
	72	>25, S*	0	10	...	0	0	0	0	25, 1*	0	0	0	0	1*	1*	1*
	200	...	...	...	...	0	0	10	0	...	0	5	3	1*	1*	1*	1*
No. 4............	24	>25, S*	>25	>25	>25	0	0	0	0	8	21, 1*	21	14	...	0	0	2*
	72	>25	>25	>25	>25	0	0	0	0	11, 9*	76, 24*	19, 8*	35, 25*	...	37, 2*	38	1, 5*
	200	...	...	...	...	0	2	0	0	...	...	...	...	...	...	...	1, 4*
No. 5............	24	>25	...	>25	>25	0	0	0	0	0	1	4, 1*	12	0	0	0	0
	72	>25, S*	...	>25	>25, S*	0	0	0	0	0	50, 26*	16, 21*	60, 16*	0	2*	1, 1*	3*
	200	...	...	...	...	0	0	1	0	4 (170)	...	12, 28*	...	2* (400)	1, 3* (144)	3* (120)	1, 4*
No. 6............	24	4	4	0	0	0	0	0	0	8, 1	0	0	0	0	0	0	...
	72	>25	>25	>25	>25	0	0	1	0	24, 8*	50	63, 8*	70	0	0	0	...
	200	...	...	...	...	13	0	1*	0	...	...	...	...	1*	2, 1*	2, 3*	...

Notes as in Table II.

TABLE IVA.—THICKNESS IN MILS (0.001 IN.) WHEN NOMINAL THICKNESS = 0.0009-IN. COPPER PLUS 0.0006-IN. NICKEL (COATING C).
Average of two readings on flat area—magne-gage method. Top reading, nickel; bottom reading, copper. Panels in same order as in Table IV.

Plater No. 2....	Panel	N126 (b) 0.94 0.76	N123 0.63 0.86	N125 0.79 0.79	N122 0.88 0.71	N127 (b) 0.81 0.66	N131 1.03 0.77	N129 0.84 0.75	N130 0.82 0.75	N152 Not Reported	N154	N153	N155	N132 Not Reported	N134	...	N151	N133 0.73 *(1)* 0.76	
Plater No. 3....	Panel	N372 (a)	N370 >2.20	N371 Total *(3)*	... ...	N376 (a) ...	N375 >2.20	N380 Total *(3)*	N378 ...	N389 Not Reported	N386	N388	N387	N381 Not Reported	N383	N382	N384	N373 0.68 *(1)* 1.01	
Plater No. 4....	Panel	N459 (a)	N457 >2.20	N456 Total *(3)*	N458	N463 (a) ...	N461 >2.20	N460 Total *(3)*	N462 ...	N468 (b) 0.40 0.90	N470 0.57 0.94	N469 0.53 0.97	N471 0.48 0.99	... (b)	N466 0.58 0.97	N465 0.51 1.05	N467 0.54 0.91	N464 0.50 *(1)* 0.84	
Plater No. 5....	Panel	N282 (a)	... >2.20	N283 Total *(3)*	N285	N287 (b) 0.54 1.01	N289 0.49 1.02	N288 0.46 0.94	N286 0.59 1.24	N294 Not Reported	N296	N295	N297	N290 Not Reported	N291	N292	N293	N284 0.59 *(1)* 0.72	
Plater No. 6....	Panel	N33 (a)	N35 >2.20	N36 Total *(3)*	N34	N38 (b) 0.62 0.62	N39 0.70 0.64	N40 0.58 0.64	N37 0.65 0.64	N48 Not Reported	N47	N45	N46	N41 Not Reported	N43	N42	...	N44 0.55 *(1)* 0.69	0.60 (2) 0.65

(3) Both copper and nickel thickness beyond range of gage used. Other notes as in Table IIA.

TABLE V.—SALT SPRAY TEST ON 0.0012-IN. NICKEL ON NAX STEEL (COATING D) SHOWING NUMBER OF RUST SPOTS ON FLAT AREA OF 4 BY 6-IN. PANEL.

Plater	Time, hr	Laboratory I				Laboratory II				Laboratory III				Laboratory IV			
		Run 1	Run 3	Run 2	Run 4	Run 1	Run 3	Run 2	Run 4	Run 1	Run 3	Run 2	Run 4	Run 1	Run 3	Run 2	Run 4
No. 1.........	24	2	1	7, 2*	1	...	1	0	0	1, 1*	0	0	22	0	1	1	0
	72	2*	5	8, 4*	9	...	2	0	0	1, 1*	0	1	24, 8*	0	4*	3*	3*
	200	...	...	...	...	...	2	2	1	2*	0	2	...	1* (400)	5*	1, 6*	7*
No. 2.........	24	11*	10	13	7	0	0	0	0	0	4, 3*	...	2	4	5	0	9, 2*
	72	3, 14*	9, 4*	10, 2*	5, 2*	0	0	0	0	1, 1*	2, 8*	...	7*	7, 3*	5, 2*	5, 4*	19, 9*
	200	...	...	...	...	1	0	1	0	2*	...	...	...	6, 5*	...	...	...
No. 3.........	24	1	15	0	8	0	0	0	...	0	3, 1*	0	0	0	0	1	0
	72	14*	20, S*	25	16	2	0	0	...	1, 2*	4*	0	0	1	1, 2*	1, 1*	1*
	200	...	...	...	...	2	2	0	...	8* (120)	...	1	1 (144)	2 (400)	9*	6*	1, 5*
No. 4.........	24	>25	12	20	9	0	0	1	0	...	5, 2*	8	5	0	0	0	1*
	72	>25, S*	>25, S*	>25, S*	>25, S*	0	0	3	0	...	6, 7*	5, 17*	20, 5*	0	3, 4*	1*	7*
	200	...	...	...	...	5, 1*	1	5, 1*	0	...	...	...	...	10* (300)	...	5, 4* (170)	...
No. 5.........	24	>25, S*	10	7	4	0	...	0	0	20, 5*	8	25, 4*	9	0	0	0	0
	72	>25, S*	>25, S*	>25, S*	>25	5	...	0	4	15, 13*	61, 27*	25, 30*	48, 12*	0	8, 5*	49, 2*	0
	200	...	...	...	...	19, 2*	...	50, 3*	1, *8	...	...	...	...	3 (400)	9, 8*	...	21, 2*
No. 6.........	24	2*	0	1	1	0	0	0	0	3, 1*	0	0	...	0	0	0	1*
	72	7, 3*	20	>25	11	0	0	0	0	3, 3*	5, 5*	9, 9*	...	1*	1	1, 1*	2*
	200	...	...	...	...	0	2	0	0	1, 5*	8, 53*	6, 34*	...	2* (400)	1, 2*	5, 3*	3*

Notes as in Table II.

TABLE VA.—THICKNESS IN MILS (0.001 IN.) WHEN NOMINAL THICKNESS = 0.0012-IN. NICKEL (COATING D).

Average of two readings on flat surface—magne-gage method.
Panels in same order as in Table V.

Plater No. 1	Panel	N178 (a) 1.09	N168 0.99	N175 1.01	N170 0.82	... (b) ...	N180 1.05	N184 1.06	N183 1.08	N195 (c) 1.06	N202 1.30	N197 1.19	N222 0.64	N192 (d) 1.12	N194 1.10	N193 1.19	N185 1.16	N179 0.88 (*1*)
Plater No. 2	Panel	N135 (a) 1.34	N136 1.18	N138 1.22	N137 1.38	N142 (d) 1.33	N139 1.38	N140 1.38	N141 1.44	N147 (c) 1.09	N149 1.20	... ...	N150 1.12	N143 (d) 1.41	N145 1.38	N144 1.32	N146 1.41	N148 1.11 (*1*)
Plater No. 3	Panel	N393 (a) 1.18	N391 1.19	N392 1.20	N390 1.13	N395 (d) 1.32	N396 1.31	N394 1.35	... ...	N405 (c) 1.10	N402 1.50	N404 1.22	N403 1.25	N398 (c) 1.20	N400 1.16	N399 1.20	N401 1.30	N397 1.32 (*1*)
Plater No. 4	Panel	N478 (a) 1.30	N476 1.27	N477 1.22	N479 1.25	N483 (a) 1.28	N482 1.17	N480 1.17	N481 1.25	... (c) ...	N490 1.19	N492 1.30	N491 1.25	N484 (b) 1.27	N486 1.18	N485 1.34	N487 1.22	N489 1.13 (*1*)
Plater No. 5	Panel	N301 (a) 0.97	N299 1.04	N298 1.22	N300 0.95	N303 (b) 1.06	... ...	N305 0.93	N302 1.06	N310 (c) 1.10	N312 1.14	N311 1.00	N313 1.20	N306 (d) 1.12	N308 1.20	N307 1.13	N309 1.16	N304 1.07 (*1*)
Plater No. 6	Panel	N49 (a) 1.04	N50 1.09	N51 1.12	N52 1.09	N54 (b) 1.18	N53 1.16	N50 1.19	N55 1.25	N63 (c) 1.00	N61 1.02	N62 1.00	... ...	N60 (d) 1.09	N58 1.06	N59 1.07	N57 1.09	N64 1.06 (*1*)

Notes as in Table IIA.

TABLE VI.—SALT SPRAY TEST ON 0.00125-IN. NICKEL ON 1010 STEEL (COATING E) SHOWING NUMBER OF RUST SPOTS ON FLAT AREA OF 4 BY 6-IN. PANEL.

Plater	Time, hr	Laboratory I				Laboratory II				Laboratory III				Laboratory IV			
		Run 1	Run 3	Run 2	Run 4	Run 1	Run 3	Run 2	Run 4	Run 1	Run 3	Run 2	Run 4	Run 1	Run 3	Run 2	Run 4
No. 1	24 72 200	2 2 ...	0 8 ...	1 2 ...	0 1 ...	0 0 1	0 0 0	0 0 0	0 0 0	0 0 0	0 0 1 (170)	0 0 3 (144)	1 2, 1* ...	... ...	0 0 0	0 2, 1* 6*	0 2* 9*
No. 2	24 72 200	5 7, 3 ...	... ...	6 10, 1* ...	6, 1* 6, 1* ...	0 1* 1, 1*	0 1 2	0 1 3	1 3 3	0 0 2* (96)	2* 1, 2* 5, 2*	1* 2, 2* ...	3 4, 1* ...	0 0 1, 2* (96)	1 1, 3* 1, 3* (96)	6 7, 2* ...	3 3, 5* ...
No. 3	24 72 200	0 >25 ...	0 >25, S* ...	1 3, 1* ...	0 12 ...	0 0 2	0 0 1	0 0 3	0 0 2	0 0 1* (120)	0 1 4, 1*	0 5, 3* 6, 3* (120)	0 0 1*	2 2 4* (400)	0 4* 5*	0 1 4*	... ...
No. 4	24 72 200	5 >25, S* ...	4 >25, S* ...	... ...	5 >25, S* ...	1 1 2	0 0 0	0 0 0	0 0 1	1 1, 1* ...	4, 1* 4, 4* ...	3, 1* 5, 6* ...	5 14, 5* ...	0 1, 5* 4* (120)	0 8, 6* 1, 9*	1 1, 2* 3, 5* (120)	5, 4* 8, 10* 8, 10*
No. 5	24 72 200	>25, S* >25, S* ...	>25 >25, S* ...	>25 >25, S* ...	>25 >25, S* ...	1 7, 7* 30, 7*	0 6 55	1 31 85, 10*	0 0 36	21, 3* 19, 6* ...	23, 10* 42, 28* ...	39, 16* 100, 50* ...	31 45, 25* ...	4 6 14, 2* (400)	... ...	0 6, 1* 26, 8*	0 3 26, 1*
No. 6	24 72 200	... ...	0 >25 ...	0 14 ...	0 2 ...	0 0 2	0 1 1	0 0 0	0 0 3	0 0 1, 5*	0 0 1, 12* (96)	1 2, 1* 4, 8*	0 1, 1* 2, 2*	0 2 1, 1* (400)	0 0 3*	0 0 3, 4*	1* 1* 1, 1*

Notes as in Table II.

TABLE VIA.—THICKNESS IN MILS (0.001 IN.) WHEN NOMINAL THICKNESS = 0.0012-IN. NICKEL (COATING E).
Average of two readings on flat surface—magne-gage method.
Panels in same order as in Table VI.

Plater No. 1....	Panel	C95 (a) 0.83	C93 1.02	C92 1.28	C94 1.01	C103 (b) 1.23	C102 1.33	C96 0.94	C101 1.10	C111 (c) 1.45	C109 1.15	C108 1.03	C110 1.15	... (d) ...	C105 1.08	C106 1.00	C107 0.92	C104 1.12 (*1*)
Plater No. 2....	Panel	C38 (b) 1.18	... ...	C41 1.24	C39 1.16	C44 (d) 1.12	C45 1.21	C42 1.14	C43 1.18	C52 (c) 1.30	C51 1.34	C50 1.50	C53 1.40	C46 (c) 1.07	C48 1.32	C47 1.20	C49 1.07	C40 1.08 (*1*)
Plater No. 3....	Panel	C152 (a) 1.33	C150 1.19	C149 1.28	C151 1.18	C156 (a) 1.30	C154 1.30	C153 1.14	C155 1.06	C161 (c) 1.30	C163 1.32	C162 1.10	C164 1.29	C157 (d) 1.21	C159 1.19	C158 1.29	... ...	C160 1.32 (*1*)
Plater No. 4....	Panel	C189 (a) 1.38	C186 1.20	... ...	C188 1.32	C190 (b) 1.32	C191 1.31	C193 1.36	C192 1.38	C199 (c) 1.30	C200 1.40	C201 1.60	C198 1.50	C194 (b) 1.31	C196 1.23	C195 1.19	C197 1.28	C187 1.15 (*1*)
Plater No. 5....	Panel	C112 (a) 1.01	C114 1.16	C113 1.13	C115 1.05	C117 (b) 1.09	C119 1.09	C118 1.03	C116 1.13	C124 (c) 1.21	C125 1.10	C126 1.02	C127 1.15	C121 (d) 1.00	... ...	C120 0.95	C123 0.92	C122 0.85 (*1*)
Plater No. 6....	Panel	... (a) ...	C3 0.96	C2 0.97	C4 0.96	C5 (b) 1.06	C6 1.11	C8 1.07	C7 1.12	C16 (c) 1.09	C15 1.07	C14 1.08	C13 1.03	C12 (c) 1.00	C10 1.01	C11 1.01	C9 0.96	C1 (e)0.94 1.00(*1*) 0.94(*2*)

Notes as in Table IIA.

TABLE VII.—SALT SPRAY TEST ON 0.00075-IN. NICKEL ON 1010 STEEL (COATING F) SHOWING NUMBER OF RUST SPOTS ON FLAT AREA OF 4 BY 6-IN. PANEL

Plater	Time hr	Laboratory I				Laboratory II				Laboratory III				Laboratory IV			
		Run 1	Run 3	Run 2	Run 4	Run 1	Run 3	Run 2	Run 4	Run 1	Run 3	Run 2	Run 4	Run 1	Run 3	Run 2	Run 4
No. 1..........	24	0	8	2	5, 2*	1*	0	0	0	...	0	0	0	0	0	0	1, 1*
	48	4, 7*	16	8	12, 6*	1*	0	2	0	...	2	0	0	0	1, 1*	0	7*
	96	3, 8*	18, 3*	20	17, 8*	1*	0	6	1	...	5, 2*	1	2	0	5, 1*	0	11*
No. 2..........	24	12, S*	3, 1*	14	20, 1*	0	...	0	0	11	11, 2*	3	15	2	4	10	2, 1*
	48	13, S*	8, 1*	13	18, 4*	1	...	0	3	14, 4*	21, 10*	2, 2*	22, 5*	10	5, 5*	8, 2*	4, 4*
	96	19, S*	1, 4*	12, 2*	20, 4*	0	...	1	3	6, 5*	33, 8*	1, 3*	25, 13*	8, 4*	11, 7*	14, 5*	3, 10*
No. 3..........	24	7, 3*	7	5	6	0	0	1	0	2	1	1, 3*	...	0	0	1*	0
	48	>25, S*	25	>25, S*	15	0	0	1	0	11	1*	1, 3*	...	0	1	1*	0
	96	>25, S*	>25, S*	>25, S*	>25, S*	0	0	4	8	16, 2*	4, 5*	4, 4*	...	3*	2*	4*	1, 4*
No. 4..........	24	>25, S*	>25	>25	>25	2	2	...	2	5, 10*	35, 4*	52, 2*	46	5	2	0	1, 1*
	48	>25, S*	>25	>25	>25, S*	3	3	...	2	5, 10*	68, 4*	98, 2*	98, 2*	3, 4*	4, 4*	1*	14, 4*
	96	>25, S*	>25, S*	>25, S*	...	15, 2*	3	...	9	6, 21*	54, 30*	74, 13*	98, 23*	7, 9*	28, 5*	2, 10*	24, 5*
No. 5..........	24	>25, S*	>25	>25	>25	2	1	5	1	67, 3*	...	30, 3*	30	0	14	1	49, 2*
	48	>25, S*	>25	>25	>25, S*	13	2	28	21	64, 11*	...	26, 12*	50, 10*	0	12, 5*	18, 1*	38, 15*
	96	>25, S*	>25, S*	>25, S*	>25, S*	50, 1*	4, 1*	60, 4*	43	59, 14*	...	26, 15*	42, 30*	1*	8, 10*	26, 4*	35, 19*
No. 6..........	24	1	2	1	0	...	0	16	0	0	0	4, 5*	0	7	0	0	1*
	48	2	14	3	0	...	0	18	0	0	6, 1*	15, 6*	13	9	2, 2*	0	2*
	96	9, S*	>25, S*	7	4	...	0	9, 8*	0	1	30, 24*	9, 12*	22, 18*	9*	1, 7*	1	2, 5*

Notes as in Table II.

TABLE VIIA.—THICKNESS IN MILS (0.001 IN.) WHEN NOMINAL THICKNESS = 0.00075-IN. NICKEL (COATING F).

Average of two readings on flat surface—magne-gage method.

Panels in same order as in Table VII.

Plater No. 1....	Panel	C75 (a) 0.71	C78 0.52	C77 0.55	C79 0.52	C82 (b) 0.56	C83 0.65	C84 0.75	C81 0.65	... (c) ...	C99 1.00	C98 0.93	C100 0.96	C85 (d) 0.79	C88 0.59	C86 0.66	C89 0.49	C97 (e) 0.90	0.90 (*1*)	
Plater No. 2....	Panel	C57 (b) 0.59	C56 0.57	C54 0.62	C55 0.60	C61 (d) 0.79	... ...	C59 0.77	C58 0.76	C69 (c) 0.83	C67 0.80	C66 0.80	C68 0.80	C64 (c) 0.65	C62 0.64	C63 0.64	C65 0.64	C60 (e) 0.84	0.80 (*1*)	
Plater No. 3....	Panel	C165 (a) 0.64	C167 0.69	C168 0.80	C166 0.78	C169 (d) 0.84	C170 0.86	C172 0.77	C171 0.79	C179 (c) 0.80	C178 0.90	C177 0.82	... ...	C173 (d) 0.77	C175 0.73	C174 0.70	C176 0.84	C180 (e) 0.89	0.77 (*1*)	
Plater No. 4....	Panel	C209 (a) 0.79	C207 0.75	C208 0.71	C206 0.72	C210 (b) 0.77	C212 0.85	... ...	C213 0.76	C218 (d) 0.80	C220 0.80	C219 0.82	C221 0.85	C214 (d) 0.72	C216 0.80	C215 0.78	C217 0.70	C211 (e) 0.73	0.67 (*1*)	
Plater No. 5....	Panel	C131 (a) 0.61	C130 0.59	C128 0.67	C129 0.67	C132 (b) 0.72	C134 0.80	C135 0.74	C133 0.63	C141 (c) 0.79	... ...	C140 0.70	C143 0.80	C139 (d) 0.73	C136 0.63	C138 0.70	C137 0.65	C142 (e) 0.71	0.70 (*1*)	0.72 (*2*)
Plater No. 6....	Panel	C17 (a) 0.62	C19 0.61	C18 0.63	C20 0.63	... (b) ...	C23 0.72	C22 0.67	C24 0.70	C32 (c) 0.68	C30 0.74	C31 0.71	C29 0.72	C28 (d) 0.66	C25 0.63	C26 0.65	C27 0.64	C21 (e) 0.67	0.67 (*1*)	

Notes as in Table IIA.

In Tables II to VII the recorded figures represent rust spots visible to the unaided eye. These failures occurred on the flat areas. Spots considered to be bigger than $\frac{1}{16}$ in. in diameter are identified by an asterisk. The results of runs 1 and 3 and those of runs 2 and 4 have been recorded side by side in order to facilitate comparison of positional effects.

From an over-all inspection of Tables II to VII, the following appears evident:

There is little or no agreement among the four testing laboratories. In terms of severity, laboratory I was consistently the most severe, followed closely by laboratory III, then laboratory IV, and lastly by laboratory II. This last laboratory was consistently the least severe, with one notable exception in Table I where it rates plater 4 the poorest.

With regard to the rating of each plater by one individual tester, there are considerable variations depending on the type of coating. Below is shown a rough approximation of how the various platers were rated by the four testing laboratories:

Laboratory	Coating	Rating of Plater (best to poorest)
I............	A	1 2 3 4 6 5
II............	A	2 6 3 1 5 4
III............	A	1 2 3 4 6 5
IV............	A	1 2 3 4 6 5
I............	B	2 3 4 5 6
II............	B	2 3 6 4 5
III............	B	2 3 6 4 5
IV............	B	5 3 2 6 4
I............	C	$6\ 3\ \overline{2\ 4\ 5}$[a]
II............	C	equal rating
III............	C	$2\ 3\ \overline{4\ 5\ 6}$
IV............	C	6 3 2 5 4
I............	D	$6\ 1\ \overline{2\ 3\ 4\ 5}$
II............	D	$\overline{1\ 2\ 3\ 4\ 6}\ 5$
III............	D	2 3 4 1 6 5
IV............	D	1 3 6 4 2 5
I............	E	1 2 6 3 4 5
II............	E	1 2 3 4 6 5
III............	E	1 6 3 2 4 5
IV............	E	1 6 3 2 5 4
I............	F	$6\ 1\ \overline{2\ 3\ 4\ 5}$
II............	F	2 1 3 4 6 5
III............	F	1 3 6 2 4 5
IV............	F	3 6 1 2 4 5

[a] Line indicates approximately equal rating.

By and large platers 4 and 5 consistently produced coatings with the lowest rating. Plater 6 prepared systems some of which rated high and some low. Platers 1, 2, and 3 were rated high by most laboratories, although here, too, there are some reversals.

Within any one test box there was poor reproducibility of test results with respect to the panels tested in the same position, as may be seen by comparing runs 1 and 3, and runs 2 and 4. The same may be said of the panels that were tested in different positions within any one box—that is, by comparing test runs 1 or 3 with 2 or 4.

With the exception of a large portion of specimens tested by laboratory II, only a minor fraction of the finishes tested by the other three laboratories met the requirements of Specification A 166.

Other broad generalizations that may be made and that are evidenced by these tests are that a copper flash under a nominal 0.0015-in. nickel coating does not appreciably lower the salt spray resistance of the coating. Laboratory I, however, rated the copper-free coating slightly above that with the copper flash. The composite coatings consisting of nominal 0.0009-in. copper plus 0.0006-in. nickel were rated lower by laboratories I and III. Tester II rated the composite coatings somewhat higher, while tester IV gave them equal rating. Nominal 0.00125-in. nickel on 1010 steel was rated better than when applied on NAX steel in three cases out of four; laboratory II gave both coatings about equal rating.

It may therefore be concluded that, with respect to the objectives of this investigation, the tests reported herein have shown that the salt spray test as operated by the four cooperating laboratories in accordance with ASTM Method

B 117 does not reliably and reproducibly prognosticate the quality of the finishes under consideration. Its value as a standard acceptance test is questionable in view of the wide divergence of test results obtained on specimens presumably plated to the same thickness by the same plater and tested by the same laboratory.

Respectfully submitted on behalf of Section B, Subcommittee III,

A. MENDIZZA,
Chairman.

REPORT OF COMMITTEE B-9

ON

METAL POWDERS AND METAL POWDER PRODUCTS*

Committee B-9 on Metal Powders and Metal Powder Products held one meeting during the year: in New York City on February 19, 1954.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, F. V. Lenel.

Vice-Chairman, J. L. Bonanno.

Secretary, C. G. Johnson.

Advisory Committee: H. R. Biehl, J. B. Haertlein, J. C. Redmond, and G. L. Werley.

NEW TENTATIVES

The committee recommends that the following method and recommended practice be accepted for publication as tentative as appended hereto:[1]

Method for Subsieve Analysis of Granular Metal Powders by Air Classification.

Recommended Practice for Hardness Testing of Cemented Carbides.

REVISION OF TENTATIVE

The committee recommends that the Tentative Specifications for Sintered Metal Powder Structural Parts from Bronze (**B 255 - 51 T**)[2] be revised as follows:

Section 4.—Change the chemical composition requirements to read as follows:

Copper, per cent	87.5 to 90.5
Tin, per cent	9.5 to 10.5
Carbon, max, per cent	1.75
Iron, max, per cent	1.0
Total other elements, max, per cent	0.5

Section 9.—Change to read as follows:

9. Structural parts shall be uniform in composition. When cut or fractured the exposed surface shall be of uniform appearance. Upon metallographic examination the microstructure of the parts shall be free of excessively large pores or incompletely alloyed areas. The parts shall be free from defects which would affect their serviceability.

Appendix.—Number the present text as Section A1 and add a new Section A2 to read as follows:

A2. A metallographic examination may be made of representative samples of each lot to determine if there is any free copper or any high tin areas present which would indicate poor sintering. The manufacturer and the purchaser may agree upon a metallographic test for quality, but, in general, a qualification test is recommended to determine this.

ADOPTION OF TENTATIVE AS STANDARD

The committee recommends that the Tentative Recommended Practice for Evaluating Cemented Carbides for Apparent Porosity (**B 276 - 52 T**)[2] be approved for reference to letter ballot of the Society for adoption as standard.

TENTATIVES CONTINUED WITHOUT REVISION

The committee recommends that the following specifications and definitions be continued as tentative in view of recommended and proposed additions and changes in each of these tentatives:

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13–18, 1954.

[1] The new tentatives were accepted by the Society and appear in the 1954 Supplement to Book of ASTM Standards, Part 2.

[2] 1952 Book of ASTM Standards, Part 2.

Specifications for:

Metal Powdered Sintered Bearings (Oil Impregnated) (B 202 - 51 T),
Sintered Metal Powder Structural Parts from Bronze (B 255 - 51 T).

Definition of:

Terms Used in Powder Metallurgy (B 243 - 49 T).

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[3]

ADVISORY COMMITTEE ACTIVITIES

The Advisory Committee held three meetings during the year to act on various committee administrative matters. A new chairman was appointed for Section A on Bearings of Subcommittee III, and Subcommittee II on Metal Powders was reorganized to form two sections, namely, Section II-A on Base Metal Powders and Section II-B on Refractory Metal Powders. Section II-A will continue the original work of Subcommittee II. W. H. Bleecker, Carmet Division of the Allegheny Ludlum Steel Corp., was appointed chairman of the newly formed Section II-B.

The Advisory Committee gave attention to the membership of the various subcommittees, and an effort will be made to increase the consumer and general interest representation. Efforts will be continued to maintain an active and participating membership.

ACTIVITIES OF SUBCOMMITTEES

The six active subcommittees and sections of Committee B-9 met twice during the year: in Cleveland, Ohio, on October 20 to 21, 1953, and prior to the main committee meeting in New York City on February 17 and 19, 1954.

Subcommittee I on Nomenclature and Technical Data (F. N. Rhines, chairman).—Approval of the term "sintering" describing a product made by sintering was deferred pending further study. Data on the mechanical properties of materials covered by Specifications for Sintered Metal Powder Structural Parts (B 222 - 52 T) were gathered by means of a questionnaire. It was decided to continue the data gathering before writing technical data sheets.

Subcommittee II on Metal Powders (J. J. Cordiano, chairman):

Section A on Base Metal Powders (J. J. Cordiano, chairman).—The Method of Subsieve Analysis of Granular Metal Powders has been approved by Committee B-9 in slightly revised form and as stated earlier in the report is recommended for publication as tentative. It was decided not to recommend for publication as tentative the proposed methods for Determination of Iron Content of Iron Powders and Methods for Determination of Insoluble Matter in Iron and Copper Powders in their present form, but to study them further. A round-robin test has been initiated on the method for determining insoluble matter. A joint task group with Committee E-3 has been appointed to which the Method for Chemical Analysis of Metal Powders and the Method for Determination of Hydrogen Loss in Metal Powder will be referred. A cooperative test program on a compressibility test has been completed; it is expected that a method for determining compressibility will result from this program. A task group is preparing a test method for determining green strength.

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[3] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

Section B on Refractory Metal Powders (W. H. Bleecker, chairman).—Three task groups were formed to study the methods now in use for particle size determination of refractory metal powders. They were concerned with the permeability method, turbidimetric methods, and photographic methods. The task groups gathered information on the details of the test methods practiced at present. On the basis of the information secured, round-robin test programs for all three methods were initiated.

Subcommittee III on Metal Powder Products (R. P. Koehring, chairman):

Section A on Bearings (S. A. Sesny, chairman).—The section has completed a thorough revision of Tentative Specifications for Metal Powder Sintered Bearings (B 202 - 51 T). Included in this revision are changes in Chemical Requirements, Radial Crushing Strength, Commercial Dimensional Tolerances, and the addition of Recommended Press Fits, Recommended Running Clearances, and a Standard Size List. These revisions and additions are now being balloted on by the section prior to submission to letter ballot of Committee B-9.

Section B on Structural Parts (P. J. Shipe, chairman).—The changes recommended in the Tentative Specifications for Bronze Structural Parts (B 255) were prepared by the section. A Tentative Specification for Copper Impregnated Structural Parts is being submitted to Committee B-9 for letter ballot. Specifications for Metallic Filter Materials are being studied.

Section C on Cemented Carbides (R. A. Canning, chairman).—The proposed Recommended Practice for Hardness Testing of Cemented Carbides was prepared by the section and as stated earlier in the report is recommended for publication as tentative. A method for the determination of density is under consideration. A procedure for classification of cemented carbides and a recommended practice for metallography are under study.

This report has been submitted to a letter ballot of the committee, which consists of 64 members; 42 members returned their ballots, of whom 37 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

F. V. LENEL,
Chairman.

C. G. JOHNSON,
Secretary.

REPORT OF ADVISORY COMMITTEE

ON

CORROSION*

The Advisory Committee on Corrosion, which during its early years held two meetings each year, has in the past few years found it necessary to hold only one meeting each year. The last meeting of the committee was held on October 2, 1953, at the Harbor Island Test Station of the International Nickel Co. at Wrightsville Beach, N. C.

The Advisory Committee on Corrosion, which elects officers in the odd-numbered years, re-elected last June F. L. LaQue as Chairman and elected Jerome Strauss as First Vice-Chairman and K. G. Compton as Second Vice-Chairman. Members-at-Large are elected each year for three-year terms. O. B. Ellis and W. H. Finkeldey were elected to serve from June, 1953, to June, 1956. Other personnel changes include the appointment of L. H. Adam, replacing J. D. Edwards as representative from Committee B-7 on Light Metals and Alloys, J. H. Gibbud for R. H. Biggs from Committee C-19 on Structural Sandwich Constructions, and D. H. Kleppinger for Sam Tour from Committee B-6 on Die-Cast Metals and Alloys.

The committee was sorry to learn of the death of Professor I. D. Mayer of Purdue University, who for many years served as the liaison at the ASTM test site on the University's grounds at Lafayette, Indiana.

The Board of Directors approved the request of the committee that Sections 5(*d*) and 6(*d*) be deleted from the Regulations Governing the Advisory Committee on Corrosion, providing for the review by the ACC of all reports of investigations concerning corrosion. This request was based on the feeling that it is impractical to give these reports any adequate review and that the technical committees preparing the reports would be more competent to judge their adequacy.

1953 EXPOSURES

Specimens were exposed during the past year at seven of the test sites and represented activity on the part of Committee A-10 on Iron-Chromium, Iron-Chromium-Nickel and Related Alloys, Committee B-3 on Corrosion of Non-Ferrous Metals and Alloys, Committee B-6 on Die-Cast Metals and Alloys, Committee B-7 on Light Metals and Alloys, Committee B-8 on Electrodeposited Metallic Coatings, the American Welding Society, and the Steel Founders Society. Details of previous exposures were given in the 1952[1] and 1953[2] Reports.

Columbus, Ohio:

The only exposures at Columbus during the past year were the specimens of the American Welding Society sprayed metal coatings exposure program.

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13–18, 1954.

[1] Report of Advisory Committee on Corrosion, *Proceedings*, Am. Soc. Testing Mats., Vol. 52, p. 212 (1952).

[2] Report of Advisory Committee on Corrosion, *Proceedings*, Am. Soc. Testing Mats., Vol. 53, p. 272 (1953).

East Chicago, Ind.:

The American Welding Society has also made exposures at this site, and in addition the Steel Founders Society has exposed a number of cast steel specimens.

Kure Beach, N. C.:

The aluminum alloy SC84 specimens previously referred to were exposed also at Kure Beach. A number of Committee B-8 specimens designed to evaluate the effect of chromate films over electroplated coatings were exposed at this location. The AWS and the Steel Founders Society also have exposed specimens here.

New York, N. Y.:

Both Committee B-6 and AWS specimens have been exposed on the Port of New York Authority roof. Subcommittee IV of Committee A-10 has exposed a number of sheets of stainless steel as used in architectural construction in an effort to evaluate the relative corrosion resistance of 17 per cent chromium and 18 per cent chromium - 8 per cent nickel steel. Zinc and iron specimens for evaluating relative corrosivity at the various test sites were added to those exposed in previous years. These latter tests are a part of the work of Subcommittee VII on Weather of Committee B-3.

Pittsburgh, Pa.:

Seventeen per cent chromium and 18 per cent chromium - 8 per cent nickel stainless steel specimens and zinc and iron calibration specimens were exposed at this location.

Point Reyes, Calif.:

Additional zinc and iron calibration specimens were mounted this past year at Point Reyes. This is also one of the locations being used by the American Welding Society as well as ASTM Committee B-7. This latter program includes 27 aluminum and 8 magnesium alloys in plate and sheet form as well as sand-cast and permanent mold tension specimens.

State College, Pa.:

The only new specimens added at this location in 1953 were additional zinc and iron specimens for corrosivity evaluation.

TEST SITE DISCONTINUED

Need by the Navy for the ground occupied by the copper-bearing and non-copper-bearing corrugated sheets of Committee A-5 at Annapolis, Md., has necessitated the discontinuation of this test site. The Annapolis site, in use since 1916, has been discontinued at the suggestion of Committee A-5 and with the subsequent approval of the Advisory Committee on Corrosion.

PRESENT FACILITIES

Specimen rack[3] and pipe frame space is available at all of the test sites established by the ACC with the exception of Tucson, Ariz. This site, chosen as representative of the hot arid regions of the southwestern part of the United States, will not be developed further until the committees interested in this area have more nearly reached the exposure stage of their contemplated programs.

To facilitate access to the Point Reyes site, the ACC cooperated with the Bell Telephone Laboratories in allotting funds for the construction of a road from the transmitting station to the test site, a distance of about three-quarters of a mile.

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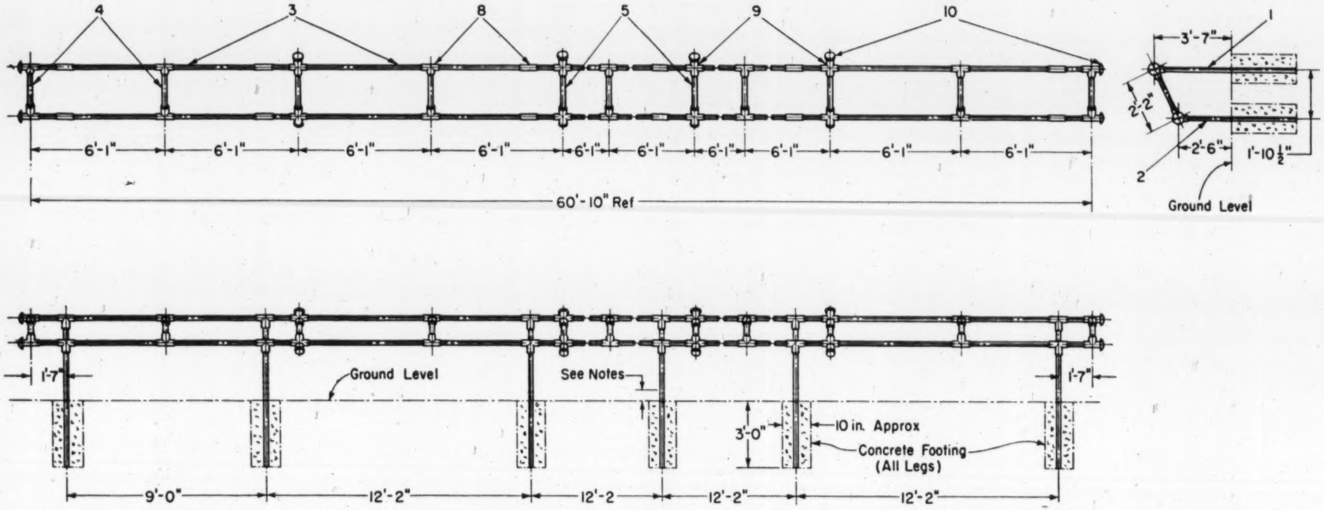
[3] "Standard" racks for exposure of 4 by 6 by ⅜-in. specimens.


4
3
8
5
9
10
1
3'-7"
2'-2"
2'-6"
1'-10½"
2
Ground Level
6'-1"
6'-1"
6'-1"
6'-1"
6'-1"
6'-1"
6'-1"
6'-1"
6'-1"
6'-1"
60'-10" Ref
1'-7"
Ground Level
See Notes
3'-0"
10 in. Approx
Concrete Footing (All Legs)
1'-7"
9'-0"
12'-2"
12'-2
12'-2"
12'-2"

NOTES:

1. Items 1, 2, 3, 4, and 5, 1¼-in. Hot Dip Galvanized Pipe.
2. Items 8, 9, and 10, tees, 4-way fittings, and plugs, respectively, manufactured by Westinghouse Electric Corp.
3. All legs filled with concrete to about 6 in. above ground line.

FIG. 1.—ASTM Pipe Frame Support for Atmospheric Exposure of Test Specimens.

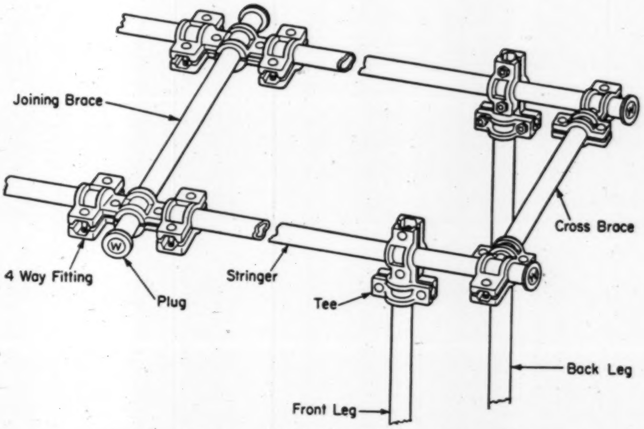


FIG. 2.— Schematic View of Support Assembly.

The test sites and facilities established by the various committees prior to the formation of the ACC have remained relatively unchanged (other than Annapolis) as detailed in the 1952[1] and 1953[2] ACC Reports. The one exception is Bridgeport, Conn. Plans were made in the spring of 1953 to reduce this area by consolidating the remaining specimens so as to provide additional space for the American Chain and Cable Co., through whose courtesy this test site area has been provided. This consolidation was effected in November, 1953, reducing the area to about 5000 sq ft.

At the suggestion of Committee A-5, the Santa Cruz, Calif., test site, which is located about three miles from the Pacific Ocean and is several hundred feet above sea level, has been reclassified from "Marine" to "Rural (marine)."

ADDITIONAL FACILITIES

Six new pipe frames were erected during the past year, three at Point Reyes, Calif., and three at Freeport, Tex. Schematic diagrams of the pipe frame assembly are shown in Figs. 1 and 2.

Two additional frames are proposed for the Freeport area, and 110 specimen racks are currently being fabricated for distribution to the various sites. Sixty of the new racks will be of Monel for the marine locations and 50 of Type 302 stainless steel for the industrial and rural sites. These additional racks will provide space for 7700 4 by 6-in. specimens. These new racks have been redesigned to permit easier mounting and removal of specimens. Details of construction are shown in Fig. 3.

TEST PROGRAMS

A number of proposed extensive exposure test programs are currently in various stages of preparation.

Committee A-5 on Corrosion of Iron and Steel plans a new series of hardware tests which will include sprayed aluminum, sprayed zinc, as well as hot-dip coatings of these metals on low-carbon and three alloy steels. The test site locations will be Kure Beach and New York.

Committee A-10 on Iron-Chromium, Iron-Chromium-Nickel and Related Al-

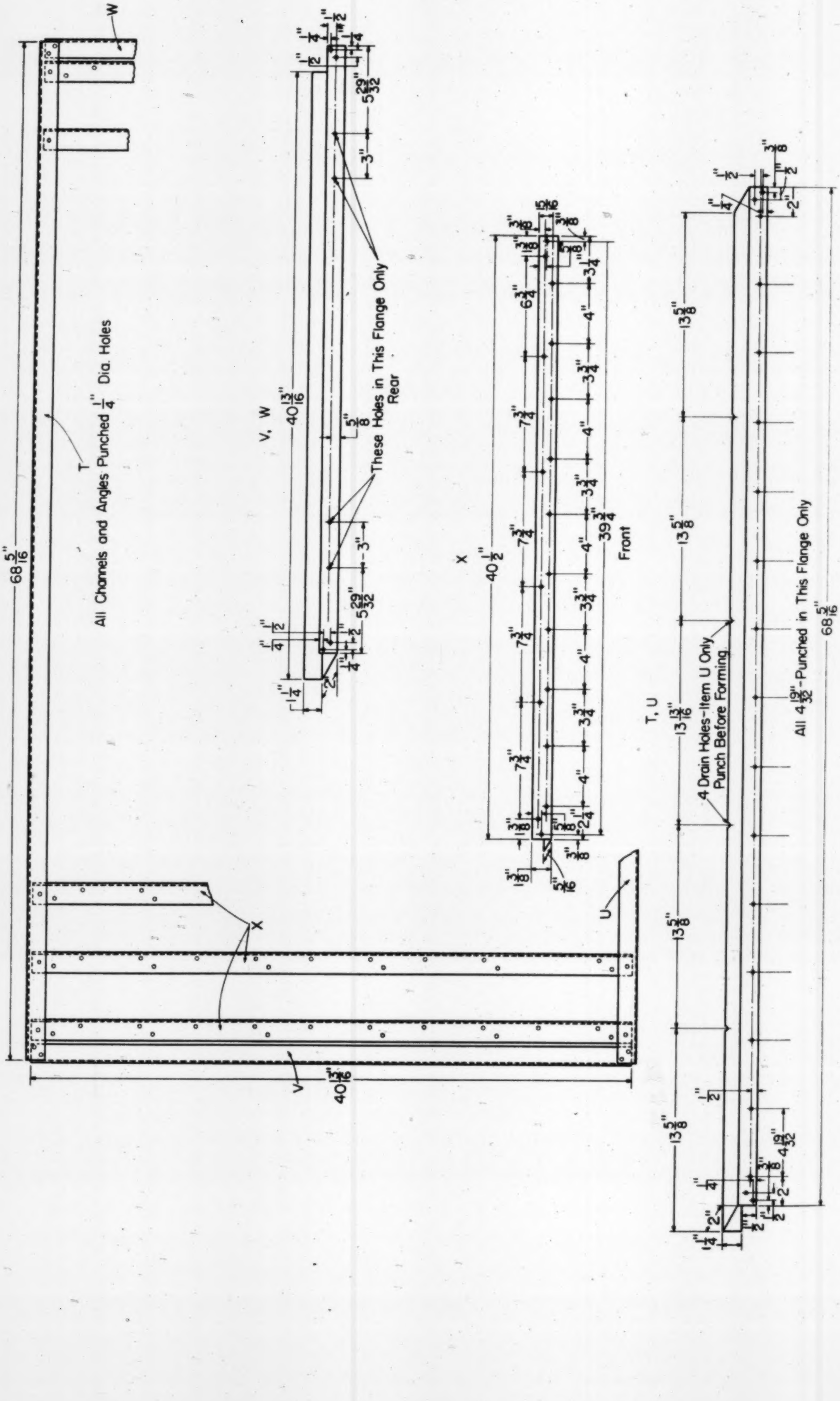

W
T
V
X
U
$68\frac{5}{16}$"
$40\frac{13}{16}$"
All Channels and Angles Punched $\frac{1}{4}$" Dia. Holes
V, W
These Holes in This Flange Only
Rear
$5\frac{29}{32}$"
3"
$\frac{5}{8}$"
X
$40\frac{1}{2}$"
$7\frac{3}{4}$"
$6\frac{3}{4}$"
$3\frac{3}{4}$"
4"
$39\frac{1}{4}$"
Front
T, U
$13\frac{5}{8}$"
$13\frac{13}{16}$"
4 Drain Holes-Item U Only
Punch Before Forming
All $4\frac{19}{32}$"-Punched in This Flange Only
$68\frac{5}{16}$"
Front

FIG. 3.—Construction Details of ASTM Standard Specimen Rack for Atmospheric Exposure of 4 by 6-in. Specimens.

loys, in addition to the special program initiated last year comparing the behavior of straight chromium with chromium-nickel steels, is currently procuring specimens for a more extensive exposure program of stainless steels.

Committee B-3 on Corrosion of Non-Ferrous Metals and Alloys is planning to expose a number of specimens which have been stored and which were not used in the non-ferrous program initiated by Subcommittee VI in 1931.

Committee B-7 on Light Metals and Alloys, Cast and Wrought, in addition to the exposure of specimens including 27 aluminum alloys and 8 magnesium alloys at New York City, N. Y.; State College, Pa.; Kure Beach, N. C.; and Point Reyes, Calif., has another series of specimens which will be mounted at Freeport, Tex.

Committee B-8 on Electrodeposited Metallic Coatings has a program planned designed to evaluate supplementary treatments of plated coatings.

Committee C-19 on Structural Sandwich Constructions, through its Subcommittee II on Permanence, Durability, and Simulated Service, is planning an extensive program of structural sandwich constructions. This work is still in the first stages of planning, size and shape of specimen and manner of exposure having yet to be decided.

The American Welding Society, although supplying its own specimen racks, has been granted permission to use pipe frame space at New York, Kure Beach, Columbus, Point Reyes, East Chicago, and Freeport. The American Welding Society program consists of more than 4000 specimens designed primarily to test the effectiveness of sprayed metal panels including coatings of aluminum and zinc in various thicknesses, some of which have additional supplementary treatments. Specimens have been mounted at all of the above locations.

Squier Signal Laboratory.—The most recent request for permission to use ASTM facilities is from the Squier Signal Laboratory to expose a number of magnesium-encased communication equipments at the Point Reyes test site. This request has been approved by the ACC, but exposure has not as yet been made.

FINANCIAL STATUS

The estimate made in 1949 was that $100,000 would be necessary to maintain adequate test site facilities over the next ten years. It is of interest to note that for the first five years expenditures totaled somewhat less than $30,000. A total of $105,150 was pledged to the test site fund, of which more than $99,000 has already been received in cash. The balance on hand as of the last meeting, including interest, was almost $73,000, $50,000 of which has been invested in savings and loan associations.

ADDITIONAL REPRESENTATION ON ACC

During the past year Committee C-22 on Porcelain Enamel has requested representation on the Advisory Committee on Corrosion and has been accepted, the representatives being the chairman of Committee C-22, W. N. Harrison, and B. J. Sweo. As provided in the "Regulations Governing Corrosion Testing" which appear in the ASTM Year Book, "Each technical committee concerned with the corrosion of metals shall designate two members, one of whom should be its chairman, who shall serve as representative members with the Advisory Committee on Corrosion." Although the Regulations specifically state corrosion of metals, the actual scope of the committee is broader, in that deterioration and weathering of any material due to environment is of interest to the group and the ASTM atmospheric exposure testing facilities are available for the use of all ASTM committees. The ACC would welcome representation from any committee interested in corrosion, weathering, or deterioration of any material falling within the Society's scope.

Respectfully submitted on behalf of the committee,

F. L. LAQUE,
Chairman.

J. S. PETTIBONE,
Secretary.

REPORT OF JOINT COMMITTEE

ON

THE EFFECT OF TEMPERATURE ON THE PROPERTIES OF METALS*

Meetings:

Meetings of the ASTM-ASME Joint Committee on the Effect of Temperature on the Properties of Metals, its panels and subcommittees were held during the past year in connection with the Annual Meetings of the ASTM in Atlantic City, N. J., during the week of June 28, 1953, and of The American Society of Mechanical Engineers in New York City the week of November 29, 1953. All of the panels met at both annual meetings excepting that on Test Methods which held a meeting at Ann Arbor, Mich., on March 10, 1954.

Technical Sessions and Papers:

The following papers were presented at the Annual Meeting of the ASME during the week of November 29, 1953, under the cosponsorship of the Petroleum and Power Divisions, Research Committee on High-Temperature Steam Generation, and the Joint Committee:

"Results of Service Test Program on Transition Welds Between Austenitic and Ferritic Steel at the Philip Sporn and Twin Branch Plants," by G. E. Lien, American Gas and Electric Service Corp., and F. Eberle and R. D. Wylie, The Babcock & Wilcox Co.

"Cyclic Heating Test, of Main Steam Piping Materials and Welds, at Sewaren Generating Station," by H. Weisberg and H. M. Soldan, Public Service Electric and Gas Co.

"Stress Rupture Properties of Austenitic Stainless Steel Weld Deposits," by R. D. Wylie, The Babcock and Wilcox Co., C. L. Corey, University of Michigan, and W. E. Leyda, The Babcock & Wilcox Co.

"Some 12 per cent Chromium Alloys for 1000 to 1200 F Operation," by D. L. Newhouse, B. R. Sequin, and E. M. Lape, General Electric Co.

"Effect of Certain Elements on the Graphitization of Steel," by R. J. Fiorentino, A. M. Hall. and J. H. Jackson, Battelle Memorial Institute.

"Comparative High Temperature Properties of British and American Steels," by W. E. Bardgett, The United Steel Cos., Ltd., England, and C. L. Clark, Timken Roller Bearing Co.

"A Critical Examination of Procedures Used in Britain and the United States to Determine Creep Stresses," by R. W. Bailey, Metro-Vickers Elec. Co., England.

"Experimental Superheater for Steam at 2000 psi and 1250 F—Progress Report after 12,000 hr of Operation," by F. Eberle, F. G. Ely, and J. A. Dillon, The Babcock & Wilcox Co.

A Symposium on Effect of Temperature on the Brittle Behavior of Metals with Particular Reference to Low Temperatures was held at the ASTM Annual Meeting under the auspices of the Low Temperature Panel. The 28 papers presented at this symposium are undergoing editing for publication in a special volume.[1]

During the 1954 Meeting of ASTM in Chicago a Symposium on Effect of Cyclic Heating and Stressing on Metals at Elevated Temperatures is being sponsored by the Committee.[2]

Membership:

There has been no change in membership during the past year.

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13–18, 1954.

[1] Issued as separate publication *ASTM STP No. 158.*

[2] Issued as separate publication *ASTM STP No. 165.*

Finances:

With the receipt during the year of a contribution of $10,000 the recent campaign for funds has been rounded out with total receipts of about $81,000. The committee gratefully acknowledges receipt during the year of an additional sum of $500 from the Engineering Foundation. The cash balance in the Custodian Account was $65,394.49 as of December 31, 1953.

Contracts:

No new research contracts were entered into during the year. The following requests for additional funds were granted:

Project DP-5 on Relaxation Data	$1000
DP-7 on Copper Base Alloys	1000
DP-3 and 4 on Super Alloys and Chromium-Molybdenum Steels	3000
GTP-1 on Effect of Stress Concentration on Fatigue of Metals at Elevated Temps	7000

A sum of $2000 was appropriated for gathering and preparing for publication under Project DP-8 data on High-Chromium and Plain Carbon Steels.

ACTIVITIES OF PANELS AND PROJECT SUBCOMMITTEES

Aviation Panel (Leo Schapiro, chairman):

Work on Project AP-1A,[3] Statistical Variations of Creep Rupture Properties of Some Sheet Materials, and on Project AP-2,[4] Properties of Some New Sheet Materials, has been completed and reports are being made at the current ASTM Meeting in Chicago. A task group of the panel is engaged in accumulating data on the elevated temperature properties of titanium with a view to determining the desirability of making a publication of such data.

Data and Publications Panel (George V. Smith, chairman):

Data on superalloys, Project DP-3, have been compiled and made ready for publication. Relaxation Test Data (Project DP-5), and data on Copper-Base Alloys (Project DP-7), and Medium-Carbon, High-Chromium and Plain-Carbon Steels (Project DP-8) are being gathered. A new subgroup has been appointed to compile information on Strength of Weldments (Project DP-6).

Gas Turbine Panel (C. T. Evans, chairman):

Work under Project GTP-1 has been extended to cover tests to determine the effect of notches of greater and less severity on the fatigue strength at 1200 and 1500 F. The work under this project covering the effect of stress concentration on the fatigue of metals at elevated temperatures is expected to be finished during the present calendar year.

This panel is cosponsoring the Symposium on Effect of Cyclic Heating and Stressing on Metals at High Temperatures[2] at the ASTM Annual Meeting in cooperation with the General Research Panel. The Panel has under consideration studies of wear, galling and fretting of spring materials and of directional (anisotropic) properties.

General Research Panel (A. J. Herzig, chairman):

The General Research Panel which has cooperated with the Gas Turbine Panel in the preparation of the Symposium on Effect of Cyclic Heating and Stressing on Metals at High Temperatures is arranging two additional symposia, one for the 1955 Spring Meeting of the ASTM on the Effect of Environment on the Strength, Scaling, or Embrittlement of Metals at Elevated Temperatures, and the other for the June, 1955, Meeting of ASTM on Metallic Materials for Service at Temperatures Above 1600 F.

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[3] A. I. Rush and J. W. Freeman, "Statistical Evaluation of the Creep-Rupture Properties of Four Heat-Resistant Alloys in Sheet Form," p. 1098, this volume.

[4] Reported in a paper by D. C. Goldberg and J. J. Lombardo on "Elevated Temperature Fatigue Properties of Several High-Temperature Sheet Materials," appended hereto, see p. 325, and in a paper being prepared by A. W. F. Green, K. Lampson, and T. Tsareff on "Thermal Shock Testing Under Stress of Certain High-Temperature Alloys," to be published in *Proceedings*, Am. Soc. Testing Mats., Vol. 55 (1955).

The panel was authorized by the Joint Committee to undertake the sponsorship of basic research in the field of creep of metals through a fellowship to be supported to the extent of $7000 over a period of 2 yr. The subject matter and the institution of learning under which the scholarship will be carried out will be recommended by a subcommittee and ultimately approved by the Executive Committee.

Low-Temperature Panel (*Irving Roberts, chairman*):

A subcommittee of the panel is conducting a survey to determine whether modification of the present 15 ft-lb minimum impact value as now stipulated by the ASME Pressure Vessel Code should be considered.

The panel is undertaking (1) a compilation of the physical and mechanical properties, other than impact, of metal at low temperatures in cooperation with the Data and Publications Panel, (2) consideration of the preparation of a manual dealing with "The Brittle Failure of Metals as Affected by Temperature," and (3) a study through a subcommittee of the advisability of conducting experimental work to determine the effects of special factors, such as section size, heat-affected zone in welding, the annealing of this zone, etc., on the properties of metals at low temperatures.

Petroleum and Chemical Panel (*C. L. Clark, chairman*):

Work on Project 8, Strength of Carbon Steels for Elevated Temperature Applications, done at the request of the ASME Boiler Code Subcommittee on Stress Allowances, has been completed and is being reported in a paper presented at the present meeting of the ASTM in Chicago.[3]

The proposal of the Task Group on the High-Temperature Strength of Weldments to determine the creep-rupture strength of welded joints of carbon and low-alloy steels was approved, and it was recommended that initial study be made of Grade B steel of A 212 (Tentative Specifications for High-Tensile-Strength Carbon-Silicon Steel Plates for Boilers and other Pressure Vessels) which is being investigated by a task group of the Steam Power Panel.

Steam Power Panel (*P. M. Brister, chairman*):

A subcommittee was appointed under Project SP-1 to study the available information on Steam and Air Oxidation of Low-Alloy Ferritic Steels. Work has been started under Project SP-2, Elevated Temperature Properties of Cast Iron, with the ultimate aim of determining the suitability of cast iron for service in the temperature range 450 to 650 F. The subcommittee handling Project SP-3 reported that there appeared to be sufficient work already under way on Type 347 austenitic welds in main steam service so that additional work was not warranted. It planned to discharge the subcommittee after it has presented a report. Materials have been obtained and work is under way on Project SP-4 to determine the Elevated Temperature Properties of SA-212B plate for use by the Boiler Code subcommittee working with the International Standards Organization toward the preparation of an International Boiler Code.

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[3] R. F. Miller, "The Strength of Carbon Steels for Elevated Temperature Applications," p. 964, this volume.

Test Methods Panel (J. J. Kanter, chairman):

Differences in opinion concerning what constitutes a practical range of temperature limitations in high-temperature testing has set up serious road blocks in the progress of the committee toward revising test methods for creep and stress-rupture testing. Recommendations have been made that a pyrometric practice subcommittee be set up under Committee E-1 of ASTM. Pending action on this recommendation, the drafting of an interim pyrometric practice for the guidance of the committee has been undertaken.

A task group was appointed to undertake the preparation of a recommended practice for notched-bar rupture testing which will serve as a guide to the designing of notches suitable for the testing of various materials.

Project 29—Effect of Certain Elements on Graphitization of Steel (J. J. Kanter, chairman):

This Project has made a final report which was presented at the Annual Meeting of the ASME in December and has been discharged. The Steam Power and the Petroleum and Chemical Panels have requested a continuation of the work of Project 29 under one of the panels of the Joint Committee.

Respectfully submitted on behalf of the committee,

F. B. FOLEY,
Chairman.
V. T. MALCOLM,
Vice-Chairman.

HOWARD C. CROSS,
Secretary.

APPENDIX

ELEVATED-TEMPERATURE FATIGUE PROPERTIES OF SEVERAL HIGH-TEMPERATURE SHEET MATERIALS*

By D. C. Goldberg[1] and J. J. Lombardo[2]

Synopsis

This paper presents the results of high-temperature fatigue tests on nine sheet materials used in fabricated gas turbine components. Six of these materials, such as Discaloy, two conditions of 19-9DL, Timken 16-25-6, HS-88, and Tinidur are relatively low alloyed materials and were tested in the temperature range of 1000 to 1350 F. Alloys L-605, V-36, and WF-31 are more highly alloyed materials and were tested from 1500 to 1800 F.

Among the materials tested in the group of relatively low alloyed materials, Timken and Tinidur have the highest endurance strengths at 1000 F. At 1200 F, four of the five alloys in this group have approximately equal strength, with 19-9DL dropping well below the others.

The three more highly alloyed materials have approximately the same fatigue strength at 1500 F as the less highly alloyed materials have at 1200 F (not considering 19-9DL). Alloy WF-31 has decidedly the highest endurance properties at 1500 F. At 1800 F, WF-31 and V-36 have approximately the same endurance strengths while that of L-605 is slightly lower.

Introduction

During 1949, it was realized by the Aviation Panel of the ASTM-ASME Joint Committee on Effect of Temperature on the Properties of Metals that the future designs of power plants would incorporate increasing quantities of high-temperature sheet materials. After reviewing the available data, it was decided to sponsor various projects under the Panel's AP-2 Committee for the purpose of increasing the knowledge of the properties of commercially available materials.

Because the potential applications for these high-temperature sheet alloys are for such gas-turbine components as fabricated turbine blades and vanes, combustion chambers, and afterburners, it was decided to conduct high-temperature stress-rupture, fatigue, thermal shock, and short-time tension tests on the selected alloys shown in Table I.

In order to eliminate the variables that could be attributed to material inconsistencies, the General Electric Co. obtained the materials in the mill-finished condition defined as hot-rolled, annealed, straightened and pickled, plus

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13–18, 1954.

[1] Supervising Engineer, Aviation Gas Turbine Division, Westinghouse Electric Corp., Philadelphia, Pa.

[2] Metallurgical Engineer, Aviation Gas Turbine Division, Westinghouse Electric Corp., Philadelphia, Pa.

TABLE I.—CHEMICAL COMPOSITION OF SHEET MATERIALS.

Material	Chemical Composition, per cent															
	Carbon	Manganese	Phosphorus	Sulfur	Silicon	Nickel	Chromium	Molybdenum	Tungsten	Titanium	Columbium	Aluminum	Iron	Boron	Nitrogen	Cobalt	Copper
19-9 DL(DL)	0.27	1.22	0.017	0.009	0.41	9.99	19.28	1.35	1.43	0.30	0.50	...	...	...	...	...	0.37
19-9 DL(D)	0.29	1.15	0.019	0.010	0.54	8.97	18.65	1.34	1.47	0.32	0.54	...	...	...	...	...	0.26
Tinidur	0.04	1.00	0.020	0.015	0.73	26.10	14.70	...	...	2.26	...	0.15	...	...	...	...	...
L-605	0.08	1.64	0.010	0.006	0.61	10.84	21.11	...	15.54	...	...	...	1.60	...	0.03	Bal.	...
V-36	0.27	0.86	0.017	0.013	0.18	19.29	24.70	4.39	2.31	...	1.71	...	1.87	...	...	44.39	...
HS-88	0.07	1.40	0.013	0.006	0.52	15.04	12.62	2.42	0.84	0.50	...	...	Bal.	0.14	...	...	...
Timken Alloy	0.084	1.70	0.017	0.011	0.40	25.00	15.93	6.00	...	...	...	...	...	...	0.132	...	...
Discaloy	0.036	1.38	...	...	1.00	26.20	13.50	3.91	...	1.61	...	0.11	Bal.	...	...	...	...
WF-31	0.136	1.42	0.009	0.016	0.42	9.93	20.34	2.61	10.69	1.03	...	...	4.13	...	...	49.00	...

TABLE II.—MILL-FINISHED CONDITION OF SHEET MATERIALS.

Material	Hot Rolled	Annealed	Pickled	Solution Treated	Air Cooled	Quenched	Aged	Time, hr	Cooled	Aged
L-605	X	X	X	2200 F	X					
Discaloy	X	X	X				1350 F	20	1200 F 5 hr	1200 F 20 hr
19-9-DL(DL)	X	X	X							
19-9-DL(D)	X	X	X							
Tinidur(T-1/T-15)						1650 F	1200 F +	16	1350 F	16 hr AC
Tinidur(T-16/T-30)						1875 F	1200 F	16	1350 F	16 hr AC
WF-31	X	X	X	2250 F	X					
Timken Alloy				1950 F	X					
V-36	X	X	X	2200 F	X					
HS-88				Hot-cold worked						

TABLE III.—FATIGUE-TEST TEMPERATURES.

Material	Fatigue Test Temperatures, deg Fahr					
	1000	1200	1350	1500	1800	Fig.
L-605				X	X	5
Discaloy	X	X	X			11
19-9 DL(DL)	X	X				10
19-9 DL(D)	X	X				9
Tinidur(T-1/T-15)	X	X				8
Tinidur(T-16/T-30)			X			8
WF-31				X	X	4
Timken Alloy	X	X				6
V-36				X	X	3
HS-88	X	X				7

any subsequent heat treatment necessary to obtain optimum properties. The materials were distributed in the form of sheared test blanks to the following testing agencies:

1. General Electric—Stress-Rupture.[3]
2. Westinghouse Electric—Fatigue.
3. Pratt & Whitney—Short Time Tension.[3]
4. Allison—Thermal Shock.

The discussion in this paper relates to

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[3] D. Preston, "Exploratory Investigation of High-Temperature Sheet Materials," *Proceedings*, Am. Soc. Testing Mats., Vol. 52, p. 962 (1952).

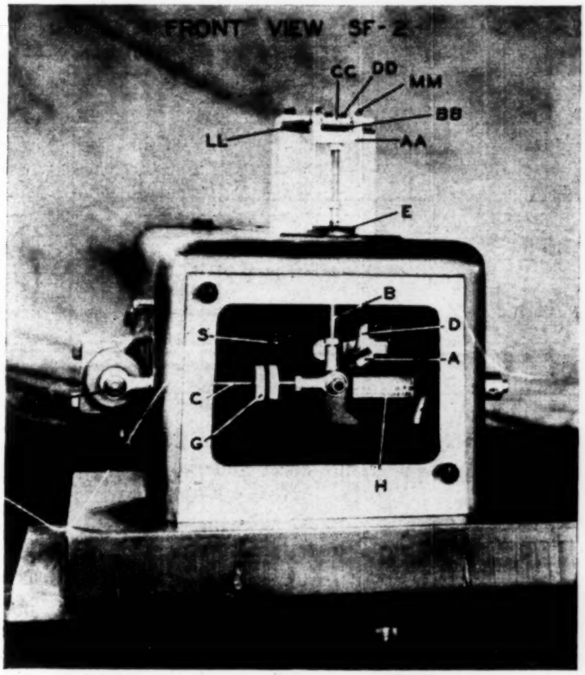

FIG. 1.—SF-2 Fatigue Machine.

A—eccentric.
B—exciting arm.
C—compensator shaft.
D—limit switch.
E—rubber scale.
G—compensator weight assembly.
H—fixed scale.
L—compensator assembly.
S—1800 RPM synchronous.
AA—loading yoke.
BB—lower specimen clamp.
CC—upper specimen clamp.
DD—specimen clamping screw.
LL—specimen bearing.
MM—bearing clamping screw.

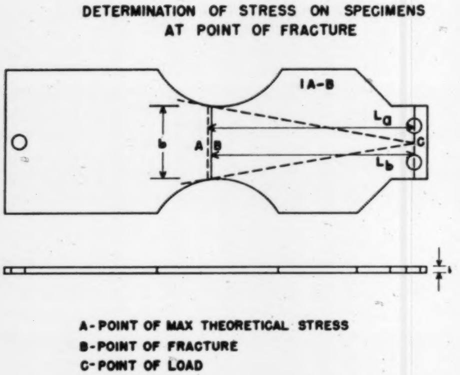
DETERMINATION OF STRESS ON SPECIMENS AT POINT OF FRACTURE
IA-B
La
Lb
b
A
B
C
t
A-POINT OF MAX THEORETICAL STRESS
B-POINT OF FRACTURE
C-POINT OF LOAD

FIG. 2.—Determination of Stress on Specimens at Point of Fracture.

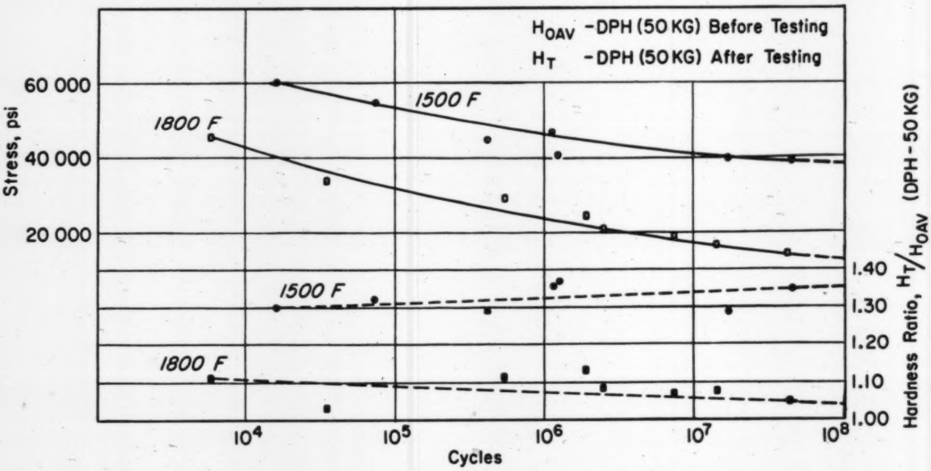

FIG. 3.—*S-N* Curves for High-Temperature Sheet Material (0.070-in. V-36 Alloy) in Reversed Bending.

the data obtained in the fatigue testing of the materials. The tensile and rupture properties of these materials have been reported by D. Preston[3] of the General Electric Co.

TEST MATERIALS

The chemical compositions of the sheet materials are shown in Table I. Tables II and III give the conditions and temperatures of test for each material.

Alloys L-605, V-36, and WF-31 are cobalt-base alloys having varying additions of nickel, chromium, molybdenum, and tungsten. Alloy V-36 has, in addition, a small amount of columbium. The remaining six materials are iron-base alloys. Only Discaloy and Tinidur were tested in the aged condition. Alloy HS-88 was tested in a hot-cold worked condition.

EXPERIMENTAL PROCEDURE

The fatigue tests were made on nine alloys at elevated temperatures in the range of 1000 to 1800 F. All tests were conducted on SF-2 fatigue machines, Fig. 1,[4] which apply a constant load at 1800 cpm. The tests were of the flexure type under zero mean stress.

The SF-2 fatigue machines, Fig. 1, were equipped with a Globar furnace which was designed by T. F. Hengstenberg of the Westinghouse Research Laboratories. The maximum variation in the temperature over the test surface ($\frac{1}{4}$-in. on each side of the maximum theoretical stress) was maintained within ±5 F throughout each test except in cases where noted in the tables. Except as

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[4] "Instructions for Installation, Operation and Maintenance of an SF-2 Machine," Baldwin-Lima-Hamilton Co., Philadelphia, Pa.

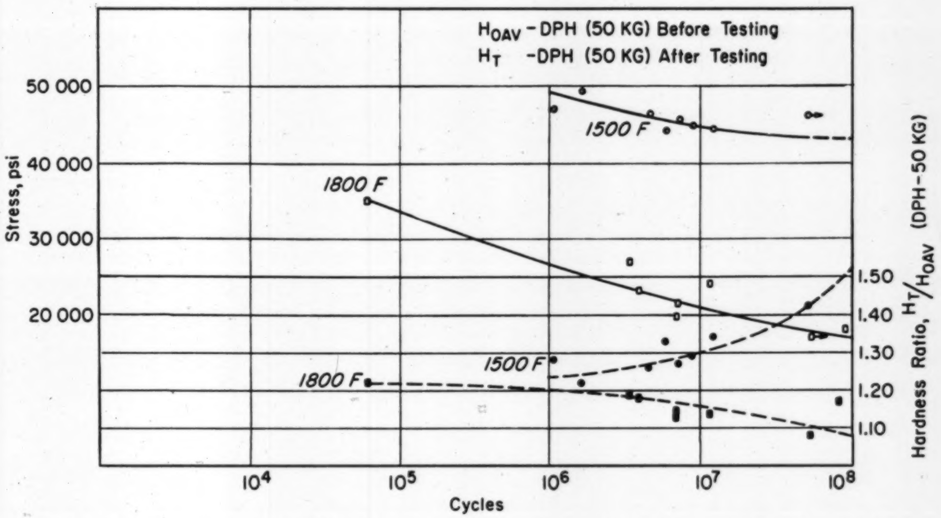

FIG. 4.—*S-N* Curves for High-Temperature Sheet Material (0.060-in. WF-31) in Reversed Bending.

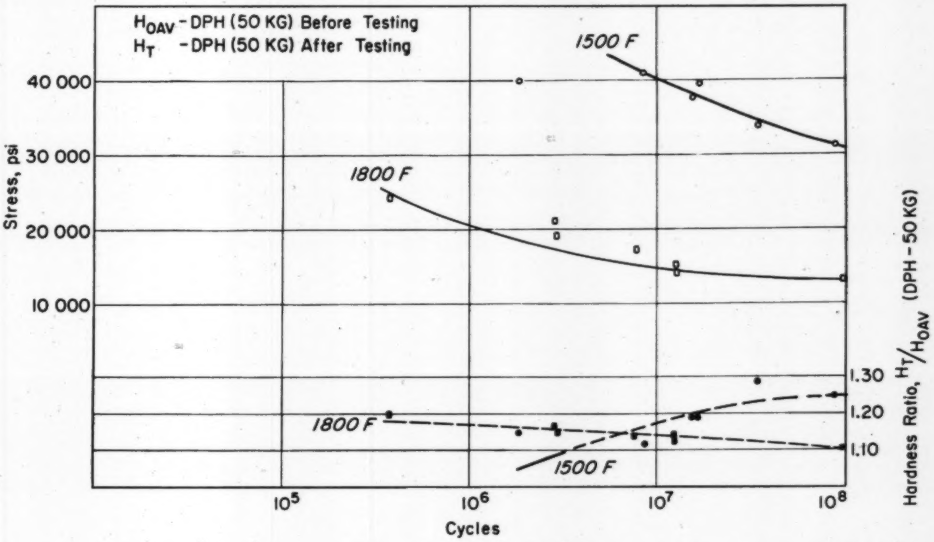

FIG. 5.—*S-N* Curves for High-Temperature Sheet Material (0.060-in. L-605) in Reversed Bending.

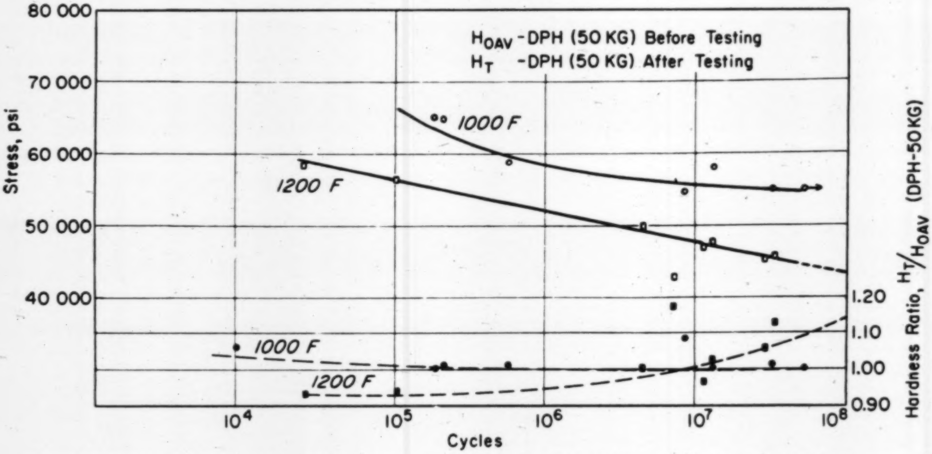

FIG. 6.—*S-N* Curves for High-Temperature Sheet Material (0.063-in. Timken Alloy) in Reversed Bending.

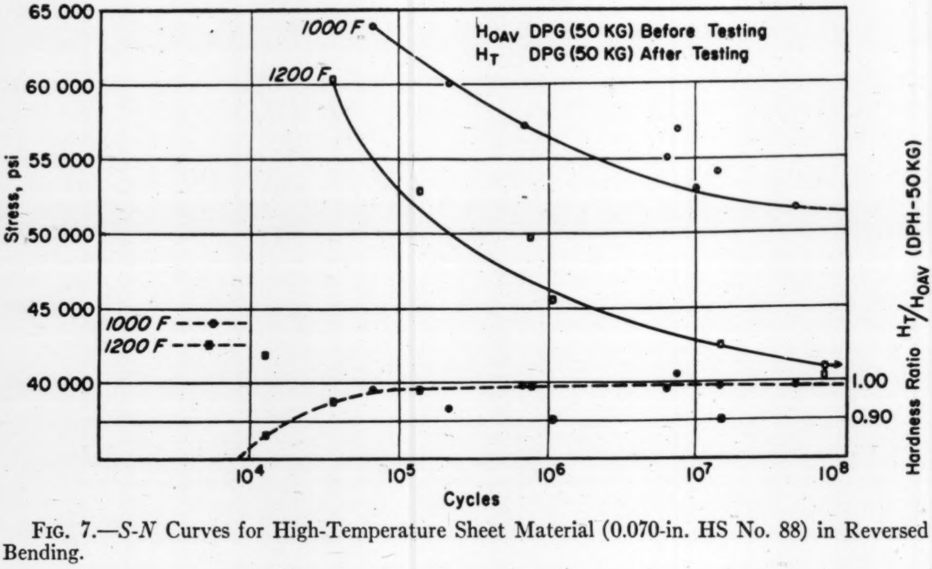

FIG. 7.—*S-N* Curves for High-Temperature Sheet Material (0.070-in. HS No. 88) in Reversed Bending.

indicated in the tables, the variation from the desired test temperature was not more than ±10 F.

Tests and calculations were conducted in the following manner:

The effective weights of the specimens were experimentally determined from both the natural frequency of vibration and the spring constant of each test specimen. The natural frequency of vibration was obtained by applying type A-7 wire strain gages mounted on the specimens at the point of maximum stress. The test specimens were then

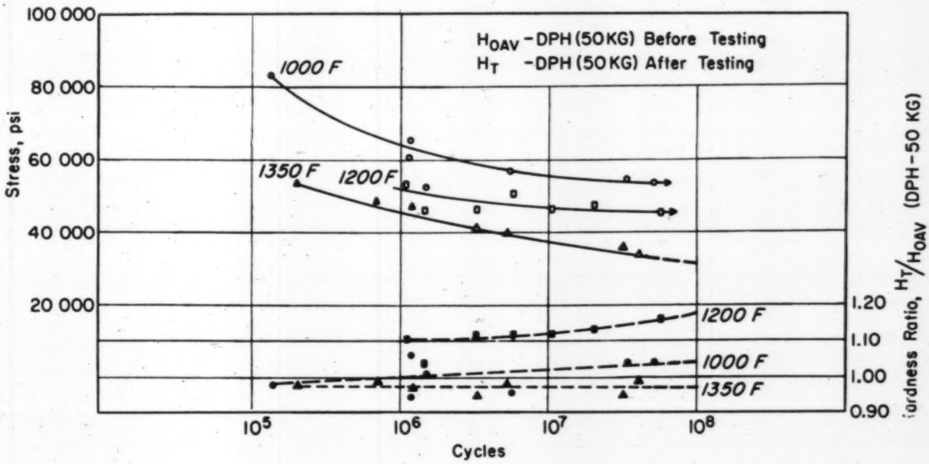

FIG. 8.—*S-N* Curves for High-Temperature Sheet Material (0.060-in. Tinidur Alloy) in Reversed Bending.

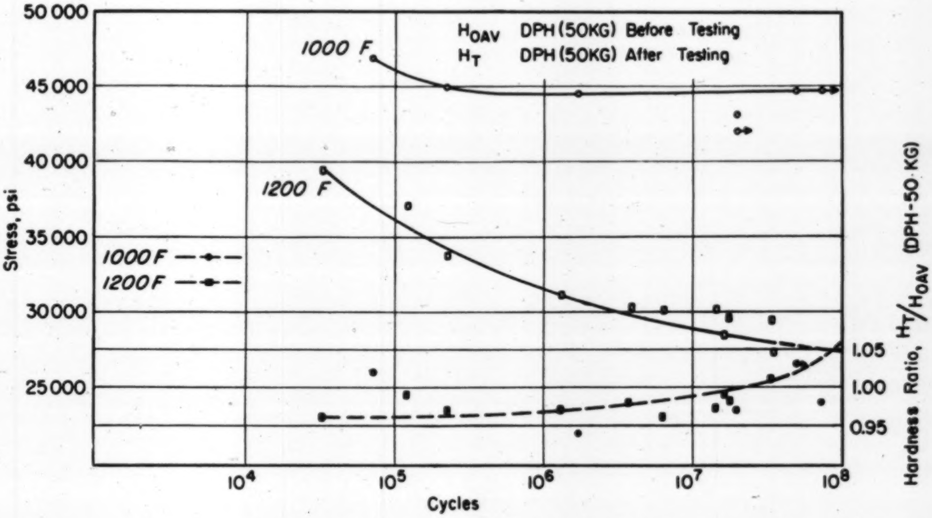

FIG. 9.—*S-N* Curves for High-Temperature Sheet Material (0.060-in. 19-9DL Code D) in Reversed Bending.

clamped in the specimen support of the SF-2 fatigue machine and the free end plucked. An oscillographic record of the natural frequencies was made. The spring constants of the specimens were determined from load *versus* deflection curves.

The formula for the determination of the effective weight used is given as follows:

$$W_e = \frac{Kg}{\omega_n^2} \quad (1)$$

where:

W_e = effective weight, lb,
K = spring constant, lb per in.,
g = acceleration of gravity, 386 in. per sec, per sec,
f_n = natural frequency, cps, and
ω_n = circular frequency, $2\pi f_n$ radians per sec.

The nominal stress at the point of fracture was calculated by using the familiar flexure formula, Stress $= \frac{Mc}{I}$.

The maximum theoretical stress occurs at point *A* or 2.875 in. from *C* as shown in Fig. 2. Point *A* is determined graphically by tangents to curved surfaces.

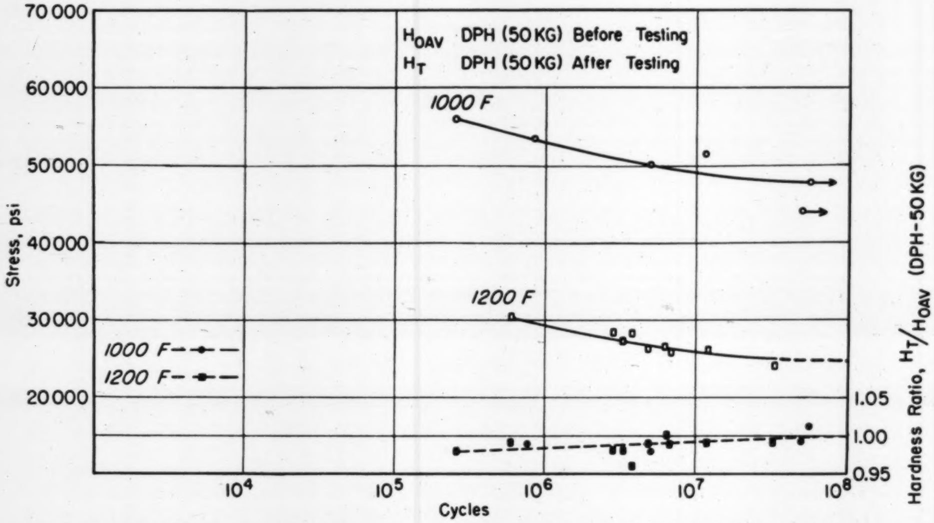

FIG. 10.—*S-N* Curves for High-Temperature Sheet Material (0.060 19-9DL Code DL) in Reversed Bending.

TEST RESULTS

The *S-N* curves for the sheet materials and conditions tested, as tabulated in Tables I, II, and III, are summarized in Figs. 3 to 11.

Also included in Figs. 3 to 11 are data indicating the ratio of the change in hardness, $\frac{H_t}{H_o}$ avg (ratio of the final hardness after test to the average hardness prior to test), of the material after test completion. An increasing ratio indicates that the material is aging under the conditions of test, while a decreasing ratio indicates an overaging or solutioning effect.

DISCUSSION OF RESULTS

The fatigue properties of the alloys considered in this paper are unquestionably influenced at elevated tempera-

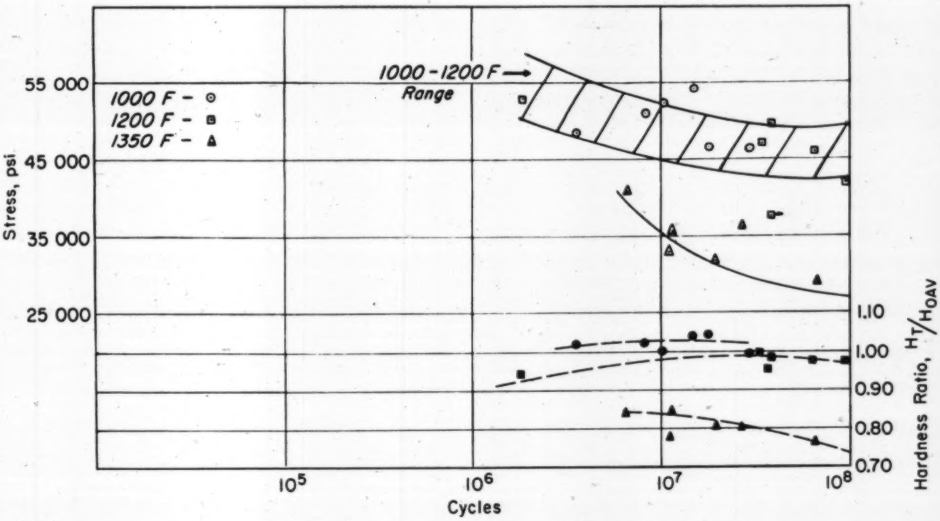

FIG. 11.—*S-N* Curves for High-Temperature Sheet Material (0.060-in. Discaloy) in Reversed Bending.

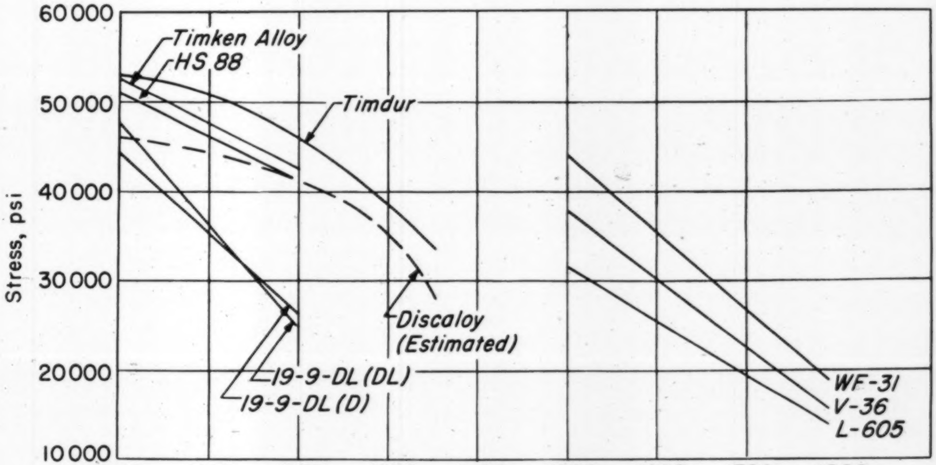

FIG. 12.—Endurance Strength of the Materials at 5 × 10^7 Cycles *versus* Temperature for Comparison.

tures by the many variables encountered in mill practice. For instance, recent unpublished work at the Materials Engineering and Research Laboratory of the Westinghouse Electric Corp. indicates that in the Discaloy and Tinidur type alloys, grain size (as resulted from solution temperature and prior rolling history) is of vital importance in its effects on the endurance limit. On the other hand, alloys which derive their elevated-temperature strength from hot-cold work are sensitive to the degree of reduction at temperatures below the normal hot-working temperature.

Therefore, the curves and data presented in Fig. 12 are largely of a preliminary nature. If design information is required, additional testing of several heats of the respective alloys would have to be accomplished.

From the tests run at 1000, 1200, and 1350 F, it is seen that the 19-9 DL (Code D and DL) drops off in endurance strength much more rapidly than Discaloy, Tinidur, HS-88, and Timken Alloy. Although the Timken and Tinidur type alloys show the highest endurance strength at 1000 F, it is seen that at 1200 F Timken, Tinidur, Discaloy and HS-88 have approximately the same strength. At 1350 F, Tinidur has a slightly higher fatigue strength than Discaloy. A study of the Tinidur data reveals that not only is the average H_0 hardness higher than for Discaloy, but that the former has continued to age at the test temperatures while the latter is stable at 1000 and 1200 F, and overages at 1350 F.

Of the three materials tested at the high-temperature range of the program, 1500 and 1800 F, the WF-31 alloy has decidedly the highest endurance strength at 1500 F. At 1800 F, the superiority of this alloy diminishes to a large extent. In fact, at the higher temperature, WF-31 and V-36 have approximately the same endurance strengths; that of L-605 is slightly lower. A comparison of the S-N curves as shown in Fig. 12 reveals that L-605 has the flattest slope.

In these three alloys a comparison of the $\frac{H_t}{H_0}$ avg curves show a completely different response to the simultaneous application of heat and stress. Alloy L-605 evidences an increase in hardness with time at 1500 F and a decrease at 1800 F. The V-36 alloy shows a uniform increase in hardness at all test times at 1500 F. At 1800 F the alloy indicates a drop in hardness. The WF-31 material reveals a striking increase in hardness at tests conducted at 1500 F with just as marked a decrease at 1800 F.

For a complete evaluation of the high-temperature superiority of these alloys, it will be necessary to consider the results of the test programs from Allison, General Electric, and Pratt & Whitney.

Acknowledgment:

We should like to acknowledge the work and effort of the Westinghouse Research Laboratories and Materials Engineering, particularly the help of T. F. Hengstenberg, M. Spewock, and Zibritosky in the actual test phases of the program.

REPORT OF COMMITTEE C-1

ON

CEMENT*

Committee C-1 held three meetings during the past year: in Atlantic City, N. J., on July 3, 1953; at Purdue University in West Lafayette, Ind., on October 21; and in Washington, D. C., on February 4, 1954.

In recognition of their generous help over the years, the following two long-time members of Committee C-1 were made Honorary Members of the committee: Ralph E. Roscoe, C-1 member since 1924, and George E. Warren, member of the committee for 21 years. At the Atlantic City gathering of the Society, Lee Walter, an Honorary Member of C-1, was honored as a 50-year member of the Society.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, R. R. Litehiser.
Vice-Chairman, W. C. Hanna.
Secretary, W. S. Weaver.

RECOMMENDATIONS ACCEPTED BY THE ADMINISTRATIVE COMMITTEE ON STANDARDS

Subsequent to the 1953 Annual Meeting, Committee C-1 presented to the Society through the Administrative Committee on Standards the following recommendations:

Tentative Revision of Standard Method of Test for:

Normal Consistency of Hydraulic Cement (C 187 - 49).

Tentative Revision of Standard Specifications for:

Masonry Cement (C 91 - 53).

These recommendations were accepted by the Standards Committee on September 9, 1953 and the tentative revisions appear in the 1953 Supplement to Book of ASTM Standards, Part 3.

NEW TENTATIVES

The committee recommends that the following specification and method of test be accepted for publication as tentative as appended hereto:[1]

Tentative Specification for Portland-Pozzolan Cement. This tentative is the result of several years of study of the related questions.

Tentative Short Method of Test for Heat of Hydration of Portland Cement. This tentative provides a method that is shorter than the Standard Method of Test for Heat of Hydration of Portland Cement (C 186 - 53); however, Method C 186 is to govern in case of dispute. The short method is essentially the same as the corresponding short method that will appear in the new text of the Federal Specification, SS-C-158c.

REVISION OF TENTATIVES

The committee recommends for revision and continuation as tentative the following:

Tentative Specifications for Air-Entraining Additions for Use in the Manufacture of Air-Entraining Portland Cement (**C 226 - 52 T**).[2]

Section 10(b).—Change to read as follows:

(*b*) *Flexural Strength*.—Tentative Method of Test for Flexural Strength of Concrete (Using Simple Beam with Center-Point Loading) (ASTM Designation: C 293 - 52 T).

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13–18, 1954.

[1] The new tentatives were accepted by the Society and appear in the 1954 Supplement to Book of ASTM Standards, Part 3.

[2] 1952 Book of ASTM Standards, Part 3.

Section 10(c).—Change to read as follows:

(c) *Resistance to Freezing and Thawing.*—Tentative Method of Test for Resistance of Concrete Specimens to Rapid Freezing and Thawing in Water (ASTM Designation: C 290 - 52 T) shall be used, except that the specimens shall be tested at the end of the 28-day curing period.

These changes are in the interest of brevity and uniformity of procedure.

Tentative Method of Test for Calcium Sulfate in Hydrated Portland Cement Mortar (**C 265 - 51 T**).[2]—Based on the results of cooperative studies completed since the acceptance of the current text of this tentative, the committee recommends that in the interest of accuracy and dependability of results the method be revised as appended hereto.[3]

TENTATIVE REVISION OF STANDARD

Standard Method of Test for Autoclave Expansion of Portland Cement (**C 151 - 53**).[4]—In answer to the question that had arisen as to what should be the standard procedure in the case of a retest under this method, the committee now recommends the following tentative revision of this standard:

Section 7: Retests.—Change to read as follows:

7. In the event of a retest, as provided in Section 9(*d*) of Specifications C 150, three specimens prepared according to Section A of Method C 151 shall be used, and the average expansion of these three specimens shall be recorded as the autoclave expansion of the sample.

ADOPTION OF TENTATIVE AS STANDARD

Tentative Specifications for Natural Cement (**C 10 - 52 T**).[2]—These specifications have been published as tentative since 1949, with minor revisions made in 1952. The committee now recommends that this tentative be adopted as standard, to replace the current Standard Specification for Natural Cement (C 10 - 37),[2] which is accordingly now recommended for withdrawal. The older specification has remained unchanged since 1937 and is apparently no longer used.

REVISION OF STANDARD, IMMEDIATE ADOPTION

The committee recommends the following revision for immediate adoption, and accordingly asks for the necessary nine-tenths affirmative vote at the Annual Meeting in order that this recommendation may be referred to letter ballot of the Society:

Standard Method of Test for Autoclave Expansion of Portland Cement (**C 151 - 53**).[4]

Section 5(b).—In line 17, change "1 hr." to "1½ hr." This change is desired in order to allow an acceptable and desirable lengthening of the cooling period.

TENTATIVES CONTINUED WITHOUT REVISION

The committee recommends that the following tentatives be continued as tentative without change at this time. Most of these tentatives are the subjects of current studies within the committee.

Tentative Methods of Test for:

Sodium Oxide and Potassium Oxide in Portland Cement by Flame Photometry (C 228 - 49 T),
Time of Setting of Hydraulic Cement in Mortar (C 229 - 52 T),[5]
Time of Setting of Hydraulic Cement by Gillmore Needles (C 266 - 51 T), and
Potential Alkali Reactivity of Cement-Aggregate Combinations (C 227 - 52 T).

Tentative Methods of Chemical Analysis of:

Portland Cement (C 114 - 51 T).

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[3] The revised method was accepted by the Society and appears in the 1954 Supplement to Book of ASTM Standards, Part 3.

[4] 1953 Supplement to Book of ASTM Standards, Part 3.

[5] See Editorial Note, p. 337.

Tentative Specifications for:

Flow Table for Use in Tests of Hydraulic Cement (C 230 - 52 T).

Tentative Definition of the Term:

Pozzolan (C 219 - 53 T).

The recommendations appearing in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[6]

ACTIVITIES OF SUBCOMMITTEES

During the year the various subcommittees have been engaged in studying many of the questions related to their respective fields. Among recent or current series of cooperative test programs have been those related to flame photometry and the short method for determining heat of hydration of cement. The effect of mechanical mixing on standard mortars forms part of a very extensive current investigation in which there is also being studied the performance of mortars when tested by a proposed method of test for flexural strength of mortar bars and for compressive strength of the resulting portions of the bars when tested as "modified" cubes. A considerable number of laboratories have been seeking improvement in the tentative test for calcium sulfate in hydrated cement mortars. Reports were made on the effects of "fluffing" the sample when making the air-permeability fineness test, also upon variables involved in the determination of the specific gravity of finely divided materials. An investigation of the tentative test for bleeding of cement pastes and mortars is engaging numerous laboratories, and thirteen laboratories are making further study of tests for sulfate resistance of cements. One new subcommittee has been studying questions related to slag cement, while another new subcommittee has but recently entered into the investigation of "false set" of cements. Matters relating to specifications for portland cements, masonry cements, and blended cements are being continuously studied by the three respective sponsoring committees.

This report has been submitted to letter ballot of the committee, which consists of 89 voting members; 80 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

R. R. LITEHISER,
Chairman.

W. S. WEAVER,
Secretary.

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[6] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee C-1 presented to the Society through the Administrative Committee on Standards the following recommendations:

Tentative Method of Test for:

Flexural Strength of Hydraulic-Cement Mortars (C 348 - 54 T), and

Compressive Strength of Hydraulic-Cement Mortars Using Portions of Prisms Broken in Flexure (C 349 - 54 T).

Revision and Reversion to Tentative of Standard Method of Test for:

Compressive Strength of Hydraulic Cement Mortars (C 109 - 52).

Withdrawal of Tentative Method of Test for:

Time of Setting of Hydraulic Cement in Mortar (C 229 - 52 T).

These recommendations were accepted by the Standards Committee on September 28, 1954, and the new and revised methods appear in the 1954 Supplement to Book of ASTM Standards, Part 3.

REPORT OF COMMITTEE C-2

ON

MAGNESIUM OXYCHLORIDE AND MAGNESIUM OXYSULFATE CEMENTS*

Committee C-2 on Magnesium Oxychloride and Magnesium Oxysulfate Cements met once during the year: on February 4, 1954, during the ASTM Committee Week in Washington, D. C.

The committee records the resignation of Lansing S. Wells as Chairman with much regret. Dr. Wells served as Chairman since the committee was formed in 1947. With the addition of one new member during the year, the committee now consists of 20 members, of whom 9 are classified as producers, 7 as consumers, and 4 as general interest members.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, D. S. Hubbell.
Vice-Chairman, A. C. Zettlemoyer.
Secretary, J. B. James.

REVISION OF STANDARD AND REVERSION TO TENTATIVE

The committee recommends that the Standard Method of Test for Ignition Loss and Active Calcium Oxide in Magnesium Oxide for Use in Magnesium Oxychloride Cements (**C 247 – 52**)[1] be revised as appended hereto[2] and reverted to tentative status. This revision is recommended because some of the laboratories have experienced difficulty in using the present method of test.

EDITORIAL CHANGES

Committee C-2 recommends editorial revisions in the following standards. Some of these changes are for the purpose of correcting errors which have been noticed since the initial publication of the standards.

Methods for Chemical Analysis of Magnesium Chloride (**C 245 – 52**):[1]

Section 6(f).—In line 5 change "weigh out 0.6 g" to read "weigh out 0.25 to 0.30 g." Change equation and definitions of terms to read:

$$N = \frac{A}{B \times 0.067}$$

where:

A = grams sodium oxalate,
B = milliliters $KMnO_4$ solution required for the titration,
N = normality of the $KMnO_4$ solution, and
0.067 = milliequivalent weight of sodium oxalate.

Section 7(a).—Change equation to read as follows:

$$A = \frac{12.5 \times 0.95B}{0.101 \times 100}$$

Section 10(a).—In lines 4 and 5 substitute "sulfate" for "SO_4."

Section 10(e).—Change the equation to read as follows:

$$\text{NaCl, per cent} = \frac{A \times 0.00292}{1.6} \times 100$$

In line 4 of the note, change "0.0012" to "0.0029."

Method of Test for Bulk Density of Magnesium Oxychloride Cements (**C 248 – 52**):[1]

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13–18, 1954.

[1] 1952 Book of ASTM Standards, Part 3.

[2] The revised method was accepted by the Society and appears in the 1954 Supplement to Book of ASTM Standards, Part 3.

Section 5(*b*).—Change the second equation to read as follows:

Bulk density, lb. per cu. ft. $= B \times 62.4$

Method for Mixing Magnesium Oxychloride Cement Compositions with Gauging Solution (for Preparation of Specimens for Laboratory Tests) (**C 251 – 52**):[1]

Section 6.—In last line, change "three" to "ten."

Methods of Test for Linear Change of Magnesium Oxychloride Cements (**C 253 – 52**):[1]

Section 7(*a*) (*2*).—Change lines 9 through 15 to read as follows:

"... graduated to at least 0.001 in. The graduations shall be such that length changes of 0.0001 in. may be estimated. When tested at any point throughout its range, the error shall not be greater than ±0.002 in. The difference between repeated measurements shall be not greater than 0.0001 in."

Section 9(*a*).—Change dimension at left of center drawing from "$\frac{3}{4}$ in." to "$\frac{3}{8}$ in."

Section 12.—In Item (*2*) of the Note change "0.*xyz* per cent" to read "±, as the case may be, 0.*xyz* per cent."

Method of Test for Setting Time of Magnesium Oxychloride Cements (**C 254 – 52**):[1]

Section 5(*a*).—In line 13 change "corresponding initial" to read "corresponding to initial."

Method of Test for Consistency of Magnesium Oxychloride Cements by the Flow Table (**C 255 – 52**):[1]

Section 2(*a*).—Change lines 6 through 8 to read as follows:

"... except that (1) the apparatus may be operated either manually or by means of a motor and (2) that the apparatus be adjusted to $\frac{1}{2}$-in. drop."

Method of Test for Flexural Strength of Magnesium Oxychloride Cements (Using Simple Bar with Two-Point or Single-Point Loading) (**C 256 – 52**):[1]

Section 4(*b*).—In line 3 change "12 hr after final set" to read "not less than 12 hr or more than 24 hr after final set."

Specifications for Oxychloride Magnesia (**C 275 – 51 T**):[1]

Section 2.—In line 8 delete "the chloride or sulfate content of."

Section 5.—In line 2 change "moisture-proof" to read "moisture resistant."

Section 6.—In Table I, line 7, change "Volume change, linear" to read "Linear change."

The recommendations appearing in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[3]

SUBCOMMITTEE ACTIVITIES

Subcommittee I on Specifications and Definitions (A. C. Zettlemoyer, chairman) is working on definitions and terms for magnesium oxychloride cements.

Subcommittee II on Methods of Test (H. H. Miller, chairman) is reporting progress on a method of test to determine wear resistance of magnesium oxychloride compositions. There are two other tests in the development stage, one to determine shear strength of bonding media and the other to determine water resistance of magnesium oxychloride cements.

This report has been submitted to letter ballot vote of the committee, which consists of 20 members; 16 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

D. S. HUBBELL,
Acting Chairman.

J. B. JAMES,
Secretary.

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[3] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

REPORT OF COMMITTEE C-3
ON
CHEMICAL-RESISTANT MORTARS*

Committee C-3 on Chemical-Resistant Mortars held three meetings during the year: on June 29, 1953, in Atlantic City, N. J.; on November 5, 1953, at ASTM Headquarters, Philadelphia, Pa.; and on February 5, 1954, in Washington, D. C.

The membership of Committee C-3 now consists of 24 members, of whom 9 are classified as producers, 7 as consumers, and 8 as general interest members. There are 3 consulting members.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, Beaumont Thomas.
Vice-Chairman, C. R. Payne.
Secretary, E. A. Reineck.

NEW TENTATIVES

The committee recommends that the Method of Test for Bond Strength of Chemical-Resistant Mortars as appended hereto[1] be accepted for publication as tentative.

ADOPTION OF TENTATIVES AS STANDARDS

The committee recommends that the following two tentatives be approved for reference to letter ballot of the Society for adoption as standard with certain editorial changes:

Tentative Method of Test for:

Chemical Resistance of Hydraulic-Cement Mortars (**C 267 – 51 T**),[2] and

Tentative Specification for:

Sulfur Mortar (**C 287 – 52 T**).[2]

The recommendations appearing in this report have been submitted to letter ballot of the Committee, the results of which will be reported at the Annual Meeting.[3]

ACTIVITIES OF SUBCOMMITTEES

Subcommittee II on Silicate Mortars (R. F. Strigle, chairman) has concentrated its efforts on the chemically setting type of silicate mortars. Tentative methods are being considered for the determination of tensile strength, compressive strength, and bond strength of these mortars, and a series of tests is being planned to determine the reliability of the test methods under consideration.

Subcommittee III on Resin Mortars (H. B. Staley, chairman) has pursued the development of a method of test for determining the water absorption of resin mortars and such a method has been developed to the point where tests to determine reliability are being planned. Consideration of methods for determining the coefficient of thermal expansion, flexural strength, and service temperature has also been initiated.

Subcommittee VIII on Bond Strength

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13–18, 1954.

[1] The new tentative was accepted by the Society and appears in the 1954 Supplement to Book of ASTM Standards, Part 3.

[2] 1952 Book of ASTM Standards, Part 3.

[3] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

(J. R. Allen, chairman) has agreed upon a method for determining bond strength which is being recommended for publication as tentative.

Subcommittee IX on Chemical Resistance (R. H. Steiner, chairman).—A method of test for chemical resistance, based on weight change, has been checked by several laboratories with results showing excellent agreement. It is planned to check another procedure for chemical resistance based on changes in tensile strength.

This report has been submitted to letter ballot of the committee, which consists of 24 members; 21 members returned their ballots, all of whom have voted affirmatively.

Respectively submitted on behalf of the committee,

BEAUMONT THOMAS,
Chairman.

J. R. ALLEN,
Secretary.

REPORT OF COMMITTEE C-4

ON

CLAY PIPE*

Committee C-4 held one meeting during the year: in Atlantic City, N. J., on June 30, 1953, at the time of the Annual Meeting of the Society. The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, J. C. Riedel.
Vice-Chairman, D. G. Miller.
Secretary, R. G. Scott.

Recommendations Accepted by the Administrative Committee on Standards

Subsequent to the Annual Meeting, Committee C-4 presented to the Society through the Administrative Committee on Standards the following recommendations:

Tentative Specification for:

Clay Flue Lining (C 315 - 53 T).

Revision of Tentative Specification for:

Extra Strength Clay Pipe (C 200 - 50 T).

These recommendations were accepted by the Standards Committee on September 9, 1953, and the new and revised specifications appear in the 1953 Supplement to Book of ASTM Standards, Part 3.

Adoption of Tentatives as Standard

Committee C-4 recommends that the following tentatives be approved for reference to letter ballot of the Society for adoption as standard with revisions as indicated:

Tentative Methods of Testing Clay Pipe (**C 301 - 52 T**),[1]

Tentative Recommended Practice for Installing Clay Sewer Pipe (**C 12 - 51 T**).[1]

Tentative Specifications for Standard Strength Clay Sewer Pipe (**C 13 - 50 T**).[1]—Revise as follows:

Section 11.—Revise editorially by the elimination of the word "plain" from the first sentence of Paragraph (*a*).

Table I.—Revise Column 3, Sand Bearing Method, to read as follows:

Size, in.	Average Strength, min, lb per linear ft
4	1500
6	1500
8	1500
10	1650
12	1800
15	2100
18	2550
21	3000
24	3600
27	4125
30	4800
33	5250
36	5850

Tentative Specifications for Standard Strength Ceramic Glazed Clay Sewer Pipe (**C 261 - 50 T**).[1]—Revise as follows:

Table I.—Make the same change as in Table I of Specifications C 13 - 50 T above.

Approval as American Standards

Committee C-4 recommends upon adoption as standard of the above tentatives that they be referred to the American Standards Association for approval as American Standard.

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13–18, 1954.

[1] 1952 Book of ASTM Standards, Part 3.

The recommendations appearing in this report have been submitted to letter ballot vote of the committee, with 24 members voting affirmatively and 0 negatively.

ACTIVITIES OF SUBCOMMITTEES

Subcommittee II on Specifications (J. O. Everhart, chairman) is continuing its study of proposed revisions in all of the clay pipe specifications with the purpose of amending their crushing strengths, basing such changes upon sound ceramic engineering data and principles.

Subcommittee III on Flue Lining (W. D. Anderson, chairman) is continuing its review of the new tentative specification for clay flue lining for the purpose of amplifying it with the addition of suitable physical and service qualifications.

This report has been submitted to letter ballot of the committee which consists of 28 members; 24 members returned their ballots, of whom 22 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

J. C. RIEDEL,
Chairman.

R. G. SCOTT,
Secretary.

REPORT OF COMMITTEE C-8

ON

REFRACTORIES*

Committee C-8 on Refractories held two meetings during the year: the eighty-fourth at Bedford Springs, Pa., on Sept. 17, 1953, and the eighty-fifth in Washington, D. C., on February 4, 1954.

At the present time there are 40 members on the committee, of whom 19 are classified as producers, 13 as consumers, and 8 as general interest members.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, R. B. Sosman.
Vice-Chairman, J. J. Hazel.
Secretary, W. R. Kerr.

RECOMMENDATIONS ACCEPTED BY THE ADMINISTRATIVE COMMITTEE ON STANDARDS

Subsequent to the 1953 Annual Meeting, Committee C-8 presented to the Society through the Administrative Committee on Standards the Tentative Classification for Single- and Double-Screened Ground Refractory Materials (C 316 – 53 T). The classification was accepted by the Standards Committee on September 9, 1953, and it appears in the 1953 Supplement to Book of ASTM Standards, Part 3.

TENTATIVE REVISIONS OF STANDARDS

Standard Definitions of Terms Relating to Refractories (**C 71 – 51**).[1] The committee recommends for publication the following tentative revision of this standard:

Add the following two definitions to the existing list of tentative revisions:

Mullite Refractories.—Refractory products consisting predominantly of mullite ($3Al_2O_3 \cdot 2SiO_2$) crystals formed either by conversion of one or more of the sillimanite group of minerals or by synthesis from appropriate materials employing either melting or sintering processes.

Silicon Carbide Refractories.—Refractory products consisting predominantly of silicon carbide.

Standard Specifications for Fireclay-Base Castable Refractories for Boiler Furnaces and Incinerators (**C 213 – 51**).[1] The committee recommends for publication the following tentative revisions of this standard:

Section 2.—Delete the last sentence. Change the Note following Section 2 to read as follows:

NOTE.—Castable refractories are furnished in coarse and fine grade. Ordinarily, coarse grade should not have more than 0.5 per cent retained on a ½-in. sieve and fine grade not more than 0.5 per cent retained on a No. 3 sieve. The particle size should be determined by the dry method of ASTM Method C 92, using a 500-g sample obtained by carefully quartering a 100-lb bag sample. Castable refractories of either the coarse or fine grade may be used for making shapes having a thick section, but when the thickness of the shape or wall is to be of the order of 2 in. or less, fine grade only should be used.

Section 3.—In line 5, delete "for class 27c or 27f."

Section 4.—In lines 5 and 6, delete "for castable refractories of class 24c or 24f."

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13–18, 1954.

[1] 1952 Book of ASTM Standards, Part 3.

Section 5.—Change to read as follows:

> 5. The castable refractory of either class 24 or class 27 shall conform with the test requirements specified in Table I.

Table I.—Delete the requirements for particle size for all four types of classes 24 and 27, including explanatory Footnote *a*.

Section 9.—Delete Paragraph (*a*), Particle Size, and renumber the subsequent paragraphs.

ADOPTION OF TENTATIVE AS STANDARD

The committee recommends that the Tentative Method of Test for Disintegration of Fireclay Refractories in an Atmosphere of Carbon Monoxide (**C 288 - 52 T**)[1] be approved for reference to letter ballot of the Society for adoption as standard with minor editorial changes.

ADOPTION OF TENTATIVE REVISION AS STANDARD

Standard Methods of Test for Crushing Strength and Modulus of Rupture of Insulating Fire Brick at Room Temperature (**C 93 - 46**).[1] The committee recommends the adoption as standard of the tentative revisions relating to Section 4 (*c*) and Section 8 (*b*) of this Standard, issued June, 1952.[2]

TENTATIVES CONTINUED WITHOUT REVISION

The committee recommends continuation of the following two methods as tentative in order to accumulate additional information on their applicability:

Tentative Method of Test for Modulus of Rupture of Castable Refractories (C 268 - 51 T), and

Tentative Method of Test for Permanent Linear Change on Firing of Castable Refractories (C 269 - 51 T).

EDITORIAL CHANGES

Standard Method of Test for Thermal Conductivity of Refractories (**C 201 - 47**),[1] and Standard Method of Test for Thermal Conductivity of Fireclay Refractories (**C 202 - 47**).[1] The committee recommends the following editorial change in these standards:

Section 1.—Add the following:

> This test method is designed for refractories having a conductivity factor of not more than 30 Btu per sq ft per hr per deg Fahr, for a thickness of 1 in.

This statement will indicate that the standard method of determining thermal conductivity is designed for refractories having a conductivity in the range of that of fireclay refractories. This addition will caution against using the method for certain special refractories of high thermal conductivity for which it might not be satisfactory.

The recommendations appearing in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[3]

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Industrial Survey (R. P. Stevens, chairman) has made progress with revision of the surveys now in the Manual and has a new survey on open-hearth and bessemer hot-metal mixers ready for editorial review.

Subcommittee II on Research (S. M. Swain, chairman) has continued its series of problems for research connected with the testing of refractories. These are being published in the ASTM BULLETIN.

Subcommittee III on Tests (S. M Phelps, chairman) has approved the recommendations on methods of test given elsewhere in this report.

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[2] 1953 Supplement to Book of ASTM Standards, Part 3.

[3] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

Section (A) on Load (A. J. Metzger, chairman) is at work on three projects: effect of design factor on modulus of rupture, miniature hot load test, and temperature distribution in the specimen brick in the standard hot load test.

Section (C) on Temperature (J. L. Carruthers, chairman) reports that the standardization project at the National Bureau of Standards for a revised table of temperature equivalents of pyrometric cones is expected to be completed in 1954 and will be offered as a revision of the Appendix to the Method of Test for Pyrometric Cone Equivalent (P.C.E.) of Refractory Materials (C 24).

Section (F) on Refractory Insulation (W. L. Stafford, chairman) is prepared to add a class 30 to the Classification of Insulating Fire Brick (C 155) as soon as three manufacturers are ready to qualify under such classification.

Section (G) on Porosity and Permanent Volume Change (S. M. Swain, chairman) reports progress on methods for the bulk density of granular refractories.

Subcommittee IX on Classifications (A. H. Couch, chairman) is still at work on a thorough revision of the Standard Classification of Fireclay Refractories (C 27 – 41). A new Section (A) on Pouring Pit Refractories (H. F. West, chairman) is collecting information on which to base a classification of ladle brick used in the ferrous metals industry.

Subcommittee X on Microscope Methods (A. W. Allen, chairman) is preparing a revised section for the Refractories Manual, on microscope techniques in the study of refractories.

Subcommittee XI on Special Refractories (H. C. Fisher, chairman) has prepared analytical methods for silicon carbide refractories of low bond content, to include the following constituents: SiC, CaO, MgO, and alkalies; these will be reviewed by Section III (E). Load test methods are in preparation. Two definitions have been adopted (see Tentative Revisions, above). It is the intention of the Subcommittee to cooperate on all points with committees of the Special Refractories Assn.

Subcommittee XII on Carbon Refractories (E. B. Snyder, chairman) has outlined test methods for reheat, thermal conductivity, permeability, oxidation, analysis for carbon, P.C.E. of ash, apparent porosity, and bulk density. These proposals will be assigned to appropriate subcommittees for review.

This report has been submitted to letter ballot of the committee, which consists of 38 members; 37 members returned their ballots, of whom 36 have voted affirmatively and 1 negatively.

Respectfully submitted on behalf of the committee,

ROBERT B. SOSMAN,
Chairman.

W. R. KERR,
Secretary.

REPORT OF COMMITTEE C-9
ON
CONCRETE AND CONCRETE AGGREGATES*

Committee C-9 on Concrete and Concrete Aggregates held three meetings last year: on July 1, 1953, during the Annual Meeting of the Society in Atlantic City, N. J.; on October 23, 1953, at Purdue University, Lafayette, Ind.; and on February 2, 1954, in Washington, D. C., during ASTM Committee Week.

On March 20, 1954, the committee suffered the loss through death of J. J. Paine, who had been a member since 1942; and on May 26, 1954, the loss of Mr. Shreve Clark, who had been a member since 1940.

During the year the committee adopted a complete set of revised statements of scopes for its subcommittees, established two new subcommittees, and reactivated one. A special subcommittee reviewed the committee's research activities and suggested extension thereof. Another special subcommittee studied the status of the 1943 edition of "Report on Significance of Tests of Concrete and Concrete Aggregates" and presented a recommendation covering a plan for a new publication. The plan was approved and the work is in progress. A revision of the Regulations Governing Committee C-9 was prepared and circulated.

Five new members were appointed to the committee during the year.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, W. H. Price.
Vice-Chairman, Fred Hubbard.
Secretary, Bryant Mather.

RECOMMENDATIONS ACCEPTED BY THE ADMINISTRATIVE COMMITTEE ON STANDARDS

Subsequent to the 1953 Annual Meeting, Committee C-9 presented to the Society through the Administrative Committee on Standards the following recommendations:

Tentative Specifications for:

Lightweight Aggregates for Structural Concrete (C 330 - 53 T), and
Lightweight Aggregates for Concrete Masonry Units (C 331 - 53 T).

These recommendations were accepted by the Standards Committee on December 16, 1953, and the new specifications appear in the 1953 Supplement to Book of ASTM Standards, Part 3.

NEW TENTATIVES

The committee recommends that the following methods be accepted for publication as tentative, as appended hereto:[1]

Tentative Methods of:

Test for Volume Change of Concrete Products, and
Test for Potential Volume Change of Cement-Aggregate Combinations.

A final report of cooperative tests conducted to acquire data for the proposed potential volume change method of test has been prepared by Subcommittee II-b and is published as an appendix to this report.[2] Complete data are also included on a proposed tentative method of test for potential abnormal expansion of cement-aggregate combinations.

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13-18, 1954.

[1] The new tentatives were accepted by the Society and appear in the 1954 Supplement to Book of ASTM Standards, Part 3.

[2] See p. 356.

REVISION OF TENTATIVES

The committee recommends for revision and continuation as tentative the following:

Tentative Method of Test for Volume Change of Cement Mortar and Concrete (**C 157 – 52 T**):[3]

Section 8(9).—Revise to read as follows:

> "Volume change data, recorded as linear expansion during moist curing and as linear contraction during dry storage, shall be reported as per cent change in linear dimension to the nearest 0.01 per cent, and"

This change is recommended because results of this test are normally cited in per cent.

Tentative Method of Test for Potential Reactivity of Aggregates (Chemical Method) (**C 289 – 52 T**):[3]

Section 4(d).—Delete this section and renumber Section 4(*e*) as 4(*d*).

Section 14.—In Paragraph (*a*), replace the semicolon in line 6 with a period and delete the subsequent portion.

In Paragraph (*b*) delete the first formula. In the descriptions of V_2 and V_3 change "neutralize the hydroxide ion" to "attain the phenolphthalein end point." Delete the descriptions of P and T.

Insert at the end of Paragraph (*a*) and at the end of line 2 of Paragraph (*b*) the word "(Note)" and add the following note to the end of Section 14:

> "NOTE.—The procedure and calculation described above shall be followed in obtaining values for R_c to be used together with S_c values to evaluate the potential reactivity of aggregates. Additional information may be obtained if a further titration is made to the methyl orange end point and additional calculations are made. After the phenolphthalein end point has been reached, add 2 or 3 drops of methyl orange solution (0.1 g of methyl orange in 100 ml of water) and titrate to the methyl orange end point. Let P equal milliliters of HCl used to obtain the phenolphthalein end point and T equal the total milliliters of acid used to obtain the methyl orange end point. Calculate a value of R_c based on the two end points, using the formula given in Section 14(*b*) substituting values of V_2 and V_3 obtained from the equation:
>
> $$V_2, V_3 = 2P - T."$$

This change is recommended to provide that tests made to evaluate aggregates by published criteria be conducted in accordance with the procedures used in establishing the criteria.

Tentative Method of Test for Flexural Strength of Concrete (Using Simple Beam with Center-Point Loading) (**C 293 – 52 T**):[3]

Section 5.—Change line 1 to read "Measurements within an accuracy of at least 0.05."

Sections 7(2) and 7(3): Delete "to the nearest 0.05 in."

These changes are recommended to improve the accuracy with which the measurements are made.

Tentative Descriptive Nomenclature of Constituents of Natural Mineral Aggregates (**C 294 – 52 T**):[3]

Section 5.—In the second sentence, change "They are silicates of aluminum, and, since they all" to "Since all feldspars."

Change the sixth sentence and remainder of section to read as follows:

> "*Orthoclase, sanidine,* and *microcline* are silicates of aluminum and potassium, and are frequently referred to as the 'potash' or potassium feldspars. The *plagioclase* feldspars include those that are silicates of aluminum and sodium, aluminum and calcium, or aluminum and both sodium and calcium. This group is frequently referred to as the 'soda-lime' group and includes a continuous series, of varying chemical composition, from *albite,* the aluminum-sodium feldspar, to *anorthite,* the aluminum-calcium feldspar, with intermediate members of the series designated *oligoclase, andesine, labradorite,* and *bytownite.* Feldspars containing potassium or sodium occur typically in granitic and rhyolitic rocks, whereas those of higher calcium content are found in rocks of lower silica content such as diorite, gabbro, andesite, and basalt."

Section 7.—Delete the third sentence. Change the last two lines to read as follows: "with effervescence only if the acid or the sample is heated or if the sample is pulverized."

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[3] 1952 Book of ASTM Standards, Part 3.

Section 9.—In line 1, after "rock" add "or other natural material." In lines 4 and 5, change "(hydrous aluminum silicates)" to read "(hydrosilicates of aluminum or magnesium or both)." In line 5, after "minerals" add "generally." In line 12, replace "changes" with "change." In line 15, after "through limestones" add "and other sedimentary rocks."

Section 10.—In line 7, change "only" to "mainly." In line 13, following "acid" add the phrase "and formation of iron oxides and hydroxides and, to a much lesser extent, sulfates."

Section 11.—In lines 4 and 8, after "brown" add "or yellowish."

Section 12.—Replace line 6 with "*laumontite*, *natrolite*, and *heulandite*, are reported to have produced deleterious effects in concrete, the latter two having been reported."

Section 13.—In line 6, before "extrusive" add "shallow-intrusive." In line 7, delete "intrusive." In line 9, delete "extrusive." In line 15, after "cooling" add "or other physicochemical conditions."

Section 14.—In Paragraph (*a*), revise second sentence to read: "The characteristic feldspars are *orthoclase*, *microcline*, or *albite*."

In Paragraph (*b*), line 3, delete "potash."

In Paragraph (*c*), lines 4 and 5, transpose the order of "biotite" and "hornblende."

In Paragraph (*d*), line 7, change "lime" to "calcium-rich."

Change Paragraph (*e*) to read as follows:

"Rocks composed almost entirely of olivine or of both olivine and pyroxene are known as peridotites. Pyroxenites are composed almost entirely of pyroxene."

Section 15.—Change the last three lines of the first paragraph to read as follows: "constituent minerals, or the rocks may be partially or wholly glassy."

In Paragraph (*a*), line 7, change "-type" to "-like." In line 12, change "synthetic" to "artificial."

In Paragraph (*b*), line 2, change "extrusive" to "igneous." In line 5, change "extrusive" to "fine-grained." In line 9, delete "at times."

Section 16.—In lines 3 and 4, change "in some cases wind action may have been important" to "wind action occasionally is important."

Section 17.—Change to read as follows:

"17. Carbonate rocks are generally referred to as *limestones* unless more than 50 per cent of the carbonate constituent is known to consist of the mineral dolomite, in which case they are called *dolomites*. If 50 to 90 per cent of the carbonate content is the mineral calcite, the rock may be called *dolomitic limestone*; if 50 to 90 per cent is the mineral dolomite, the rock may be called *calcitic dolomite*. Most carbonate rocks contain some noncarbonate impurities such as silica minerals, clay, organic matter, or hydrous calcium sulfate (gypsum). Carbonate rocks containing 10 to 50 per cent sand are *arenaceous* (or *sandy*) *limestones* (or *dolomites*); those containing 10 to 50 per cent clay are *argillaceous* (or *clayey* or *shaly*) limestones (or *dolomites*). *Marl* is a clayey limestone which is fine-grained and commonly soft. Very soft carbonate rocks are known as chalk or '*lime rock*.' Limestone recrystallized by metamorphism is known as *marble*."

"NOTE.—'Magnesium limestone' is sometimes applied to dolomitic limestones and calcitic dolomites but it is ambiguous and its use should be avoided. The term 'lime rock' also is not recommended."

Section 18.—In Paragraph (*a*), line 4, change "larger than sand" to "of gravel." In line 9, after "if" add "the grains and the cement are largely quartz and." In line 14, after "material" add "of sandstone."

Change Paragraph (*b*) to read as follows:

"*Graywacke* is sandstone containing abundant dark particles of rocks, such as chert, slate, phyllite, and schists, in addition to mineral grains and a matrix resembling shale or slate."

Section 19.—In line 3, after "soft" add "and massive." In line 6, after "harder" add "and platy." In line 10, after "these" add "metamorphic."

Section 20.—Revise line 1 to read as follows: "Chert is a very fine-grained siliceous rock which." In line 9, delete "in color." In line 16 change "black" to "green." In line 28, before "in sands" add "as particles."

Section 21.—In line 3, change "described" to "mentioned."

Section 22.—In line 2, following "green" add "to almost black." In line 3, after "from" insert "silica-poor."

Section 23.—In line 6, after "micas" insert "; and of granular minerals, usually quartz and feldspars."

These changes are recommended to improve technical accuracy and provide increased clarity.

TENTATIVE REVISION OF STANDARD

The committee recommends tentative revisions of the Standard Definitions of Terms Relating to Concrete and Concrete Aggregates (**C 125 – 48**)[3] as follows:

Add the following new definitions:

"*Bleeding.*—The autogenous flow of mixing water within, or its emergence from, freshly placed concrete or mortar."

"*Workability of Concrete.*—That property determining the effort required to manipulate a freshly mixed quantity of concrete with minimum loss of homogeneity."

These definitions have been prepared in accordance with requests approved by the committee, referred to its subcommittee on definitions for action, and are as reported by that subcommittee.

ADOPTION OF TENTATIVES AS STANDARD

The committee recommends that the following tentatives which have stood without revision for two or more years be approved for reference to letter ballot of the Society for adoption as standard:

Tentative Method of:

Making and Curing Concrete Compression and Flexure Test Specimens in the Laboratory (**C 192 – 52 T**),[3] with editorial revisions as follows:

Section 10(c).—Following the mention of plaster capping materials, insert a reference to the following note which should be added to the end of the section:

"NOTE.—Low-strength molding plasters are unsatisfactory for use in capping strength specimens. Special high-strength plasters only have been found satisfactory. The following two plasters are considered to be in this classification: 'Hydrostone' and 'Hydrocal White'."

Tentative Method of:

Sampling Fresh Concrete (**C 172 – 52 T**),[3]

Test for Air Content of Freshly Mixed Concrete by the Pressure Method (**C 231 – 52 T**),[3]

Testing Air-Entraining Admixtures for Concrete (**C 233 – 52 T**),[3,3a]

Test for Comparing Concretes on the Basis of the Bond Developed with Reinforcing Steel (**C 234 – 49 T**),[3] and

Test for Soft Particles in Coarse Aggregates (**C 235 – 49 T**).[3]

Tentative Recommended Practice for:

Petrographic Examination of Aggregates for Concrete (**C 295 – 52 T**).[3]

Tentative Specifications for:

Air-Entraining Admixtures for Concrete (**C 260 – 52 T**).[3]

ADOPTION OF TENTATIVE REVISION AS STANDARD

The committee recommends that the tentative revisions of the Standard Method of Test for Cement Content of Hardened Portland-Cement Concrete (**C 85 – 42**),[3] issued June 1952,[3] be ap-

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[3a] See Editorial Note, p. 355.

proved for reference to letter ballot of the Society for adoption as standard.

Revision of Standard, Immediate Adoption

The committee recommends for immediate adoption revisions of one of its standards, as set forth below, and accordingly asks for the necessary nine-tenths affirmative vote at the Annual Meeting in order that these revisions may be referred to letter ballot of the Society:

Standard Specifications for Ready-Mixed Concrete (**C 94 – 48**):[3,3a]

Section 1(a).—Change to read as follows:

"These specifications cover the requirements for ready-mixed concrete. Requirements for quality of materials and for proportions and quality of concrete shall be either as hereinafter specified or as specified by the purchaser by reference to applicable general specifications for concrete. In any case where the requirements of such general specifications are in conflict with these specifications the requirements of the general specifications shall govern unless otherwise specified by the purchaser."

Section 3.—Change designation of Paragraph (*b*) to "(*4*) Admixtures," and revise to read as follows:

"(4) *Admixtures.*—When air-entraining concrete is specified and an admixture is used to secure the desired air content, the admixture shall conform to the Tentative Specifications for Air-Entraining Admixtures for Concrete (ASTM Designation: C 260 T). Admixtures other than those used exclusively for the entrainment of air shall not be permitted unless provided for in the contract or in the designated applicable specifications."

Section 4.—In Note 1, first sentence, change "shall" to "should."

Change Paragraph (*a*) (5) for Alternate No. 1 and Paragraph (*a*) (4) for Alternate No. 2 to read as follows:

"When air-entraining concrete is specified, the maximum and minimum limits for air content of samples taken from the transportation unit at the point of discharge (Note 2)."

Add the following to Note 2:

"The required air content may be produced by use of an air-entraining cement, an air-entraining admixture, or a combination of the two."

Change Paragraph (*b*) for Alternate No. 1 to read as follows:

"(*b*) Prior to the actual delivery of the concrete, the manufacturer shall furnish a statement to the purchaser giving the properties of the materials and the proportions by weight (dry) of cement and of fine and coarse aggregates that are proposed to be used in the manufacture of each class of concrete ordered by the purchaser."

In Note 3, first sentence, change "shall" to "should."

Change Paragraph (4) (*b*) for Alternate No. 2 to read as follows:

"Prior to the execution of the contract, the manufacturer shall furnish a statement to the purchaser, giving the proportions by weight (dry) of cement and of fine and coarse aggregates that will be used in the manufacture of each class of concrete ordered by the purchaser. He shall also furnish evidence satisfactory to the purchaser that the proportions selected will produce concrete of the quality specified."

Section 7(a).—Change to read as follows:

"(*a*) Bins with adequate separate compartments for fine aggregates and for each required size of coarse aggregate shall be provided in the batching plant. Each compartment shall be designed to discharge efficiently and freely into the weighing hopper. Means of control shall be provided so that, as the quantity desired in the weighing hopper is approached, the material may be added slowly and shut off with precision. A port or other opening for removing an overload and sampling materials from the hopper shall be provided. Weighing hoppers shall be constructed so as to eliminate accumulations of tare materials and to discharge fully."

Section 8.—Change Paragraph (*a*) to read as follows:

"(*a*) Mixers may be stationary mixers or truck mixers. Agitators may be truck mixers or truck agitators. Each mixer and agitator shall have attached thereto in a prominent place a metal plate or plates on which are plainly marked, for the various uses for which the equipment is designed, the capacity of the drum or container in terms of the volume of mixed concrete and the speed of rotation of the mixing drum, blades, or paddles. Stationary mixers shall be equipped with an acceptable timing device that will not permit the batch to be discharged until the specified mixing time has elapsed. Truck mixers shall be equipped with means by which the number of revolutions of the drum, blades or paddles may be readily verified."

Change Paragraph (*e*) to read as follows:

"(*e*) Use of the equipment may be permitted under conditions determined by the purchaser when operation with a longer mixing time or with a smaller load will permit the requirements of Paragraph (*d*) to be met."

Section 13.—Change to read as follows:

"13. Slump tests shall be made at the option of the purchaser. Determinations of air content shall be made at the option of the purchaser if air-entraining cement or an air-entraining admixture is used. If the measured slump or air content falls outside the limits specified, a check test shall be made immediately on another portion of the same sample. In the event of a second failure, the purchaser may refuse to permit the use of the load of concrete represented."

Section 15(c).—Change to read as follows by the addition of the italicized words:

"(*c*) The representative of the purchaser shall ascertain and record *the delivery ticket number for the concrete and* the exact location in the work at which each load represented by a strength test is deposited."

These revisions are proposed to clarify various provisions of the specifications.

WITHDRAWAL OF STANDARD

The committee recommends that the Standard Specification for Lightweight Aggregates for Concrete (**C 130 – 42**) be withdrawn. This standard is being replaced by Specifications C 330 – 53 T and C 331 – 53 T, referred to earlier in the report as having been accepted by the Administrative Committee on Standards, and by the Specification for Lightweight Aggregates for Insulating Concrete which is under development.

TENTATIVES CONTINUED WITHOUT REVISION

The committee recommends that the following tentatives, which have stood without revision for two or more years, be retained as tentative, since the subcommittee concerned with each of them has reported that significant revisions thereof are in preparation:

Tentative Specifications for:

Concrete Aggregates (C 33 – 52 T).[3a]

Tentative Method of Test for:[3a]

Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate (C 88 – 46 T),
Air Content (Volumetric) of Freshly Mixed Concrete (C 173 – 42 T),
Fundamental Transverse and Torsional Frequencies of Concrete Specimens (C 215 – 52 T)
Resistance of Concrete Specimens to Rapid Freezing and Thawing in Water (C 290 – 52 T),
Resistance of Concrete Specimens to Rapid Freezing in Air and Thawing in Water (C 291 – 52 T), and
Resistance of Concrete Specimens to Slow Freezing and Thawing in Water or Brine (C 292 – 52 T).

EDITORIAL CHANGE

The committee recommends the following editorial change in the Standard Method of Making and Curing Concrete Compression and Flexure Test Specimens in the Field (**C 31 – 49**):[3]

Section 6(c): Following the mention of plaster capping materials, insert a reference to the following note which note should be inserted at the end of the section:

"NOTE.—Low-strength molding plasters are unsatisfactory for use in capping strength specimens. Special high-strength plasters only have been found satisfactory. The following two plasters are considered to be in this classification: 'Hydrostone' and 'Hydrocal White'."

This change is designed to provide a specific indication of what is intended by the existing provision.

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[4]

SUBCOMMITTEE ACTIVITIES

The work of Committee C-9 is carried out by an Executive Subcommittee and three groups of other subcommittees: Group I, Administration, Fred Hubbard, chairman; Group II, Research, A. T. Goldbeck, chairman; and Group III, Specifications and Test Methods, Stanton Walker, chairman. All the subcommittees have been active during the year, and many of those that have not been responsible for recommendations included in this report may be expected to have such recommendations in the near future.

At the October, 1953, meeting revised statements of scopes of the subcommittees in the three groups were adopted. The subcommittee work of the committee may be best summarized by tabulating these 29 scopes:

GROUP I—ADMINISTRATION

It shall be the function of this group to perform all of those administrative duties of the committee assigned to it by the Executive Subcommittee. It shall be the duty of the group chairman to guide, coordinate, and advise the various Group I Subcommittees in their respective endeavors.

Subcommittee I-a, Finance:

To be responsible for the proper handling of the funds of the committee; to study the financial needs of the committee and initiate means for raising funds when necessary and as directed by the Executive Subcommittee.

Subcommittee I-b, Papers and Symposia:

To solicit papers and symposia on specific subjects dealing with the various phases of concrete and concrete aggregates for presentation at the annual meeting and other meetings of the committee, or for publication as general information.

Subcommittee I-c, Sanford E. Thompson Award:

To review each year all papers on concrete and concrete aggregates which qualify under the governing rules as being eligible for the award, and report its findings to the Chairman of Committee C-9.

Subcommittee I-d, Editorial and Definitions:

To review committee research papers, tentatives, and standards for conformity with Society procedures and policies, and to define technical terms in connection with committee activities.

Subcommittee I-e, Membership:

To solicit new members for the Society, especially those who might be interested in concrete and concrete aggregates, and to serve in a follow-up capacity either by personal call or correspondence in soliciting the membership of persons referred to it as prospects.

GROUP II—RESEARCH

It shall be the function of this group to suggest, receive suggestions, and initiate research pertaining to concrete and concrete aggregates. It shall be the duty of the Group Chairman to guide, coordinate, and advise the various Group II Subcommittees in their respective endeavors.

Subcommittee II-a, Evaluation of Data:

To develop procedures for the evaluation of data and encourage the use of statistical methods in the field of concrete and concrete aggregates.

Subcommittee II-b, Chemical Reactions of Aggregates in Concrete:

To investigate the chemical reactivity of aggregates in concrete and their effects on the properties of concrete

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[4] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

Subcommittee II-c, Elastic and Plastic Properties of Concrete:

To investigate the elastic and plastic properties of concrete as they may be affected by various influences such as magnitude of stress, period of application, moisture condition, and stress repetition.

Subcommittee II-d, Durability of Concrete:

To determine and classify the conditions affecting the durability of concrete and to encourage and initiate in various organizations the correlation of laboratory studies with field performance.

Subcommittee II-e, Dynamic Testing of Concrete:

To develop information and test methods for determining the properties of concrete by dynamic methods in the laboratory or in structures without damaging the concrete and to determine the significance of the tests.

Subcommittee II-f, Aggregate Mineralogical Characteristics as Related to Concrete:

To develop information on the effects of mineral composition of aggregates on the properties of concrete.

Subcommittee II-g, Pore Structure of Aggregates:

To develop means for determining the size, shape, volume, and other characteristics of pores in aggregates and to study their significance in relation to properties of concrete.

GROUP III—SPECIFICATIONS AND METHODS OF TESTING

It shall be the function of this group to develop and maintain specifications and methods of testing concrete and concrete aggregates. It shall be the duty of the Group Chairman to guide, coordinate, and advise the various Group III Subcommittees in their respective endeavors.

Subcommittee III-a, Methods of Testing Concrete for Strength:

To develop and maintain methods of testing concrete for strength.

Subcommittee III-b, Methods of Testing for Volume Changes of Concrete and Concrete Aggregates:

To develop and maintain methods of testing for volume changes of concrete and concrete aggregates.

Subcommittee III-c, Methods of Testing Fresh Concrete:

To develop and maintain methods of sampling fresh concrete and of testing it for slump, flow, unit weight, air content, and other properties not specifically assigned to other subcommittees.

Subcommittee III-d, Specifications for Concrete Aggregates:

To develop and maintain specifications for concrete aggregates, other than for lightweight aggregates.

Subcommittee III-e, Methods of Testing Concrete Aggregates for Physical Characteristics:

To develop and maintain methods of testing concrete aggregates, except lightweight aggregates, for such properties as grading, unit weight, voids, specific gravity, moisture content, mortar-making properties, hardness, resistance to abrasion, and soundness.

Subcommittee III-f, Methods of Testing and Specifications for Lightweight Aggregates for Concrete:

To develop and maintain methods of testing and specifications for lightweight aggregates for concrete.

Subcommittee III-g, Methods of Testing and Specifications for Materials Used in Curing Concrete:

To develop and maintain methods of testing and specifications for materials used in curing concrete.

Subcommittee III-h, Methods of Testing an Specifications for Admixtures:

To develop and maintain methods of testing and specifications for admixtures used in concrete.

Subcommittee III-i, Methods of Testing and Specifications for Ready-Mixed Concrete:

To develop and maintain methods of testing and specifications for ready-mixed concrete.

Subcommittee III-j, Methods of Testing Concrete for Bleeding:

To develop and maintain methods of testing concrete for bleeding.

Subcommittee III-k, Methods of Testing Concrete for Bond:

To develop and maintain methods of testing for evaluating bond between concrete and other substances as it is influenced by the properties of the concrete.

Subcommittee III-l, Miscellaneous Tests of Hardened Concrete:

To develop and maintain methods of testing hardened concrete for cement content and other properties not specifically assigned to other subcommittees.

Subcommittee III-m, Methods of Testing Concrete for Resistance to Abrasion:

To develop and maintain methods of testing concrete for resistance to abrasion.

Subcommittee III-n, Methods of Testing Setting Time of Concrete:

To develop and maintain methods of testing for determining the setting time of concrete.

Subcommittee III-o, Methods of Testing Concrete for Resistance to Weathering:

To develop and maintain methods of testing concrete for resistance to freezing and thawing, wetting and drying, and heating and cooling; and to correlate the results of such tests with the properties of concrete and concrete aggregates.

Subcommittee III-p, Manual of Testing Concrete and Concrete Aggregates:

To develop and maintain a Manual of Testing Concrete and Concrete Aggregates to aid in the proper application of current ASTM methods of testing concrete and concrete aggregates.

Subcommittee III-q, Methods of Testing and Specifications for Packaged Dry Pre-Mixed Materials for Concrete:

To develop and maintain methods of testing and specifications for packaged dry pre-mixed materials for concrete.

This report has been submitted to letter ballot of the committee, which consists of 125 members commanding 98 votes, plus 6 honorary members having voting privileges; 109 members returned their ballots, of whom 105 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

L. W. TELLER,
Chairman.

BRYANT MATHER,
Secretary.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee C-9 presented to the Society through the Administrative Committee on Standards the following recommendations:

Tentative Specifications for:

Fly Ash for Use as an Admixture for Portland-Cement Concrete (C 350 – 54 T), and
Lightweight Aggregates for Insulating Concrete (C 332 – 54 T).

Revision of Tentative Specifications for:

Concrete Aggregates (C 33 – 52 T).

Revision of Tentative Methods of Test for:

Fly Ash as an Admixture for Portland-Cement Concrete (C 311 – 53 T).

Tentative Revision of Standard Method of Testing:

Air-Entraining Admixtures for Concrete (C 233 – 54).

Revision and Reversion to Tentative of Standard Specifications for:

Ready-Mixed Concrete (C 94 – 48)

Tentative Specifications C 332 were accepted by the Standards Committee on November 5, 1954, and the remaining recommendations were accepted on September 28, 1954; all appear in the 1954 Supplement to Book of ASTM Standards, Part 3.

APPENDIX

FINAL REPORT ON COOPERATIVE TESTS ON PROPOSED TENTATIVE METHOD OF TEST FOR POTENTIAL VOLUME CHANGE OF CEMENT-AGGREGATE COMBINATIONS AND PROPOSED TENTATIVE METHOD OF TEST FOR POTENTIAL ABNORMAL EXPANSION OF CEMENT-AGGREGATE COMBINATIONS

At its meeting in Cincinnati, Ohio, on March 6, 1951, Subcommittee II-b on Chemical Reactions of Aggregates in Concrete of ASTM Committee C-9 on Concrete and Concrete Aggregates authorized a cooperative program of tests to establish the reproducibility of two methods of test recommended to the subcommittee for evaluating the response of cement-aggregate combinations to wetting and drying and heating and cooling by measuring length change of mortar and concrete specimens.

The proposed Method of Test for Potential Abnormal Expansion of Cement-Aggregate Combinations was compiled by William Lerch on behalf of Subcommittee II-b, based on original investigations by C. H. Scholer (**1**).[1]

The proposed Tentative Method of Test for Potential Volume Change of Cement-Aggregate Combinations[2] was proposed by A. D. Conrow as a result of his extensive studies later reported to the Society in detail (**2**).

Arrangements were made for participation of six laboratories in the cooperative tests, a detailed procedure was developed, and cements and aggregates were distributed to participating laboratories from two central sources. Mix design data for all cement-aggregate combinations were developed in the Engineering Laboratories of the Bureau of Reclamation. All necessary materials and instructions were in the hands of participants by the end of December, 1951. A summary of interim results of the cooperative tests was published by the Society (**3**).

COOPERATING LABORATORIES

Participants in the cooperative tests were as follows:

Laboratory[3]	Principal
Portland Cement Assn., Chicago, Ill.	William Lerch
Bureau of Reclamation, Denver, Colo.	W. H. Price
Ash Grove Lime and Portland Cement Co., Chanute, Kans.	A. D. Conrow
Waterways Experiment Station, Jackson, Miss.	Bryant Mather
Kansas State College, Manhattan, Kans.	C. H. Scholer
University of California, Berkeley, Calif.	R. E. Davis

CEMENTS USED

Three cements were supplied by the Bureau of Reclamation for use in both procedures (Table I). For the proposed Tentative Method of Test for Potential Volume Change of Cement-Aggregate Combinations (Conrow test), 15 lb of each cement were shipped, each in a sealed container. For the proposed Method of Test for Potential Abnormal Expansion of Cement-Aggregate Combinations (Scholer test), 75 lb of each of the three cements were shipped, each lot in a sealed metal container.

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[1] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 373.

[2] This tentative was accepted by the Society and appears in the 1954 Supplement to Book of ASTM Standards, Part 3, as Tentative Method C 342 - 54 T.

[3] The order in which the laboratories are named in this list does not correspond with the numerical sequence indicated in Tables II and IV.

TABLE I.—CHEMICAL ANALYSIS AND PHYSICAL PROPERTIES OF CEMENTS USED IN THE COOPERATIVE TESTS.

Property	Cement		
	No. 7488	No. 2448	No. 9406
Chemical composition, per cent:			
SiO_2	21.66	23.16	22.13
Al_2O_3	5.58	4.39	5.88
Fe_2O_3	2.54	3.84	4.28
CaO	63.85	64.46	62.89
MgO	1.58	1.36	1.68
SO_3	2.10	1.22	2.10
Loss on ignition	1.60	0.62	0.93
Na_2O	1.16	0.30	0.03
K_2O	0.04	0.42	0.20
Insoluble residue	0.11	0.16	0.25
Compound composition, per cent:			
C_3S	48.1	46.9	36.1
C_2S	25.9	31.1	36.2
C_3A	10.5	5.1	8.3
C_4AF	7.7	11.7	13.0
Physical properties[a]:			
Fineness (Method C 204), sq cm per g	3460	3160	3510
Fineness (Method C 115), sq cm per g	1780	1850	1880
Amount retained on No. 325 sieve (Method C 115), per cent	12.3	4.6	8.4
Autoclave expansion (Method C 151), per cent	0.049	0.015	−0.010
Time of setting (Method C 266):			
Initial, min	230	240	220
Final, hr	5	6	6⅙
Air content of mortar (Method C 185), per cent by volume	5.6	5.5	8.1
Compressive strength (Method C 109):			
1 day in moist air, 2 days in water	1440	...	1790
1 day in moist air, 6 days in water	2310	2230	2340
1 day in moist air, 27 days in water	3690	3800	3825
Specific gravity (Method C 188)	3.10	3.19	3.18
Normal consistency (Method C 187), per cent	24.2	23.8	24.0

[a] The methods referred to appear in the 1952 Book of ASTM Standards or the 1953 Supplement to Book of ASTM Standards, Part 3.

AGGREGATES USED

Selection of the Aggregates:

Aggregates that had been tested and used extensively in construction were selected for use in the program. Gravel and sand from the Columbia River near Coulee City, Wash., were used in construction of Grand Coulee Dam and are known to be superior in all respects. Sand and gravel from Clear Creek near Denver, Colo., have been used extensively in concrete construction in and near Denver and have been used as a control aggregate in many laboratory investigations by the Bureau of Reclamation. They are known to be of satisfactory quality and to be not deleteriously reactive with portland cement.

Sand and gravel from the Republican River near St. Francis, Kans., have been used extensively in concrete construction in that vicinity and have been tested in many laboratories throughout the country. The

Republican River sand and gravel are notorious for their participation in adverse cement-aggregate reactions involving both high- and low-alkali cements (4).

Samples of the aggregates were prepared to permit comparison of the results of the Conrow test on mortars with results of the Scholer test on concrete beams.

Petrography of the Aggregates:

The aggregates used in the cooperative tests were analyzed petrographically in accordance with ASTM Recommended Practice C 295[4] in the Petrographic Laboratory of the Bureau of Reclamation. The results are summarized in detail in a memorandum (5) distributed to members of Subcommittee II-b.

Sand and Gravel, Columbia River near Coulee City, Wash.—The gravel from the Columbia River near Coulee City, Wash., is composed mainly of basalts and granites; also present are lesser proportions of monzonites, porphyritic monzonites, quartz monzonite porphyries, diorites, andesites, vein quartz, quartzites, granite gneisses, sandstones, metasandstones, argillites, and siltstones. Very small proportions of clay lumps, amphipolites, chalcedonic cherts, chalcedonic siltstones, limestones, zeolites, and epidote-chlorite rock are also present. The zeolite thomsonite constitutes about 0.1 per cent of the sample, being a sparse constituent of certain facies of the basalt. Particles considered to be unsound physically constitute an average of 0.1 per cent of the size fractions of coarse aggregate; particles of inferior physical quality constitute an average of 6.7 per cent of the various fractions. Andesites, chalcedonic cherts, and chalcedonic siltstones, which are considered to be potentially reactive with cement alkalies, constitute an average of 1.3 per cent of the several fractions. The pebbles are predominantly subangular or angular, approximately 16 per cent being splintery or tabular.

The sand from the Columbia River near Coulee City, Wash., is composed chiefly of basalts. Small proportions of quartz, granites, feldspars, and other rock types observed in the related gravel also are present. The fine fractions of the sand contain very small amounts of biotite, devitrified volcanic glass, hematite, hornblende, palagonite, basaltic hornblende, augite, zircon, epidote, and chalcedony. Particles considered to be physically unsound are present in trace amounts; particles of inferior physical quality constitute 9.8 per cent of the sand. Andesites and chalcedony, which are considered to be potentially reactive with cement alkalies, constitute 0.05 per cent of the sand. The particles are predominantly angular to subangular.

Sand and Gravel, Clear Creek near Denver, Colo.—The gravel from Clear Creek near Denver, Colo., is composed mainly of granite; smaller amounts of quartz, feldspars, and gneisses, and very small amounts of quartzites, amphibolites, schists, argillites, chalcedonic cherts, rhyolites, basalts, and latite porphyries are present. The entire sample is characterized by a slight to moderate degree of weathering. Deeply weathered or otherwise physically unsound particles constitute an average of 12.0 per cent by weight of the three size fractions. Particles of inferior physical quality constitute an average of 28.4 per cent of the three size fractions. Chalcedonic cherts, chalcedony, rhyolites, and latite porphyries, which are considered to be potentially deleteriously reactive with cement alkalies, constitute an average of 3.9 per cent of the several size fractions. The pebbles are predominantly angular, about 30 per cent being subround or subangular.

The coarse sand from Clear Creek is composed chiefly of the rock types observed in the related gravel. The fine fractions of the sand are composed mainly of quartz; moderate amounts of feldspars and small amounts of the several rock types, magnetite, hornblende, augite, biotite, muscovite, epidote, zircon, and iron oxides, are present. Unsound particles constitute 11.6 per cent of the sand. Additional particles of inferior quality constitute 4.0 per cent of the sand. The particles classified as unsound are mainly individual crystals of feldspars. Rock types considered to be potentially deleteriously reactive with cement alkalies constitute 0.9 per cent of the sand; these are

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[4] Tentative Recommended Practice for Petrographic Examination of Aggregates for Concrete (C 295 - 52 T), 1952 Book of ASTM Standards, Part 3, p. 978.

TABLE II--SUMMARY OF RESULTS OF COOPERATIVE TESTS--PROPOSED TENTATIVE METHOD OF TEST FOR POTENTIAL VOLUME CHANGE OF CEMENT-A
Subcommittee II-b, ASTM C
Mortar expansions in percent and range corr

																			Age (days)--exp	
Cooperating Laboratory	28		36		44		45		51		72		100		128		156		184	
	Expansion (percent)	Range	Expansion (percent)	Range	Expansion (percent)	Range	Expansion (percent)	Range	Expansion (percent)	Range	Expansion (percent)	Range	Expansion (percent)	Range	Expansion (percent)	Range	Expansion (percent)	Range	Expansion (percent)	Range
HIGH-ALKALI CEMENT AND GRAND C																				
1	0.008	0.008	0.015	0.010	-0.073	0.008	-0.013	0.010	-0.001	0.010	0.004	0.013	0.007	0.008	0.006	0.008	0.007	0.009	0.007	0.010
1/ 2	.011	.006	.017	.004	-.070	.010	-.009	.006	.001	.003	.006	.003	.010	.006	.010	.004	.013	.004	.013	.005
3	.008	.001	.014	.002	-.077	.002	-.019	.004	-.006	.002	.001	.000	.002	.001	.004	.001	.004	.001	.005	.001
4	.010	.001	.013	.004	-.083	.005	-.022	.002	-.016	.002	-.005	.008	-.001	.008	-.004	.010	-.001	.003	.001	.010
5	.010	.006	.015	.003	-.082	.005	-.016	.004	-.004	.002	.004	.003	.004	.003	.009	.003	.009	.005	.009	.002
6	.008	.003	.013	.002	-.086	.005	-.021	.004	-.008	.002	-.002	.004	.002	.005	.002	.005	.003	.003	.004 2/	.004
3/ Average	.009	.003	.014	.004	-.078	.016	-.017	.013	-.006	.017	.001	.011	.004	.011	.004	.014	.006	.014	.006	.012
MEDIUM-ALKALI CEMENT AND GRAND																				
1	.004	.003	.008	.004	-.070	.003	-.023	.003	-.010	.003	-.003	.004	-.001	.004	-.002	.004	.001	.003	.002	.004
1/ 2	.006	.002	.009	.004	-.070	.005	-.018	.007	-.007	.003	-.003	.003	.002	.005	.003	.004	.006	.002	.005	.003
3	.006	.002	.008	.001	-.072	.007	-.026	.005	-.013	.002	-.004	.002	-.001	.002	.000	.002	.001	.001	.002	.001
4	.008	.001	.008	.003	-.074	.006	-.028	.008	-.019	.008	-.008	.007	-.005	.008	-.008	.008	-.004	.007	-.001	.008
5	.009	.004	.008	.002	-.073	.007	-.021	.002	-.009	.012	-.001	.004	-.001	.003	.005	.002	.006	.003	.005	.003
6	.005	.002	.006	.002	-.080	.004	-.028	.002	-.015	.003	-.006	.002	-.002	.002	-.002	.001	-.001	.002	.000 2/	.003
Average	.006	.005	.008	.003	-.073	.010	-.024	.010	-.012	.012	-.004	.007	-.001	.007	-.001	.013	.002	.010	.002	.006
LOW-ALKALI CEMENT AND GRAND C																				
1	.004	.005	.006	.003	-.065	.005	-.017	.003	-.005	.003	.000	.003	.001	.002	.001	.002	.003	.002	.003	.002
1/ 2	.005	.004	.006	.004	-.065	.007	-.016	.005	-.006	.006	.000	.002	.003	.002	.004	.003	.005	.003	.005	.003
3	.004	.001	.006	.002	-.074	.002	-.024	.004	-.009	.003	-.004	.003	-.002	.002	.000	.002	.000	.002	.000	.002
4	.008	.002	.007	.003	-.074	.008	-.022	.007	-.013	.007	-.003	.005	-.001	.004	-.005	.003	-.002	.004	.000	.005
5	.004	.003	.008	.004	-.075	.005	-.016	.003	-.008	.004	.002	.004	.003	.003	.005	.003	.007	.002	.006	.002
6	.005	.002	.006	.003	-.078	.007	-.023	.006	-.009	.004	-.004	.004	-.001	.004	.000	.005	.000	.005	.001 2/	.006
Average	.005	.004	.006	.002	-.072	.013	-.020	.008	-.008	.008	-.002	.006	.000	.005	.001	.010	.002	.009	.002	.006
HIGH-ALKALI CEMENT AND CLEAR C																				
1	.009	.002	.021	.005	-.069	.005	-.010	.006	.003	.005	.009	.008	.010	.005	.010	.005	.013	.006	.013	.005
1/ 2	.011	.003	.021	.002	-.071	.005	-.005	.007	.004	.001	.010	.003	.014	.003	.014	.002	.016	.002	.017	.002
3	.009	.001	.020	.003	-.077	.004	-.016	.005	-.002	.003	.005	.002	.006	.001	.008	.002	.009	.002	.010	.002
4	.011	.003	.018	.003	-.079	.004	-.020	.003	-.009	.003	-.002	.001	.002	.004	.002	.004	.005	.005	.008	.005
5	.009	.002	.020	.003	-.077	.003	-.008	.002	.000	.001	.005	.004	.008	.005	.013	.005	.015	.006	.015	.003
6	.010	.003	.019	.003	-.083	.005	-.017	.006	-.003	.006	.002	.005	.005	.005	.007	.006	.008	.005	.009 2/	.007
Average	.010	.002	.020	.003	-.076	.014	-.013	.015	-.001	.013	.005	.012	.008	.012	.009	.012	.011	.011	.012	.009
MEDIUM-ALKALI CEMENT AND CLEAR																				
1	.006	.003	.010	.004	-.063	.004	-.021	.004	-.006	.005	.002	.006	.005	.005	.006	.005	.008	.006	.008	.006
1/ 2	.007	.003	.012	.004	-.065	.003	-.020	.009	-.005	.007	.004	.003	.008	.003	.010	.003	.012	.006	.012	.007
3	.007	.002	.011	.003	-.067	.006	-.024	.004	-.008	.005	.002	.006	.005	.004	.008	.004	.009	.004	.011	.004
4	.008	.002	.012	.003	-.068	.003	-.026	.002	-.011	.002	.001	.006	.008	.004	.011	.006	.013	.008	.015	.008
5	.006	.001	.012	.004	-.065	.003	-.018	.002	-.006	.003	.006	.003	.009	.004	.015	.004	.018	.004	.019	.004
6	.007	.006	.010	.006	-.072	.007	-.024	.008	-.008	.005	.000	.007	.005	.005	.008	.008	.008	.008	.010 2/	.007
Average	.007	.002	.011	.002	-.067	.009	-.022	.008	-.007	.006	.002	.006	.007	.004	.010	.009	.011	.010	.012	.011
LOW-ALKALI CEMENT AND CLEAR CR																				
1	.006	.003	.011	.004	-.060	.005	-.014	.003	-.001	.005	.007	.005	.009	.003	.010	.004	.012	.005	.012	.004
1/ 2	.008	.005	.014	.006	-.056	.007	-.008	.010	.003	.005	.010	.004	.013	.006	.014	.005	.016	.004	.017	.003
3	.006	.002	.011	.003	-.068	.002	-.020	.003	-.004	.003	.002	.003	.005	.004	.007	.004	.008	.004	.008	.003
4	.007	.003	.010	.003	-.072	.003	-.023	.005	-.010	.007	-.002	.007	.001	.006	.001	.007	.003	.006	.004	.006
5	.007	.004	.012	.003	-.065	.010	-.015	.002	-.003	.001	.007	.003	.008	.005	.013	.005	.016	.005	.016	.006
6	.006	.006	.010	.007	-.075	.007	-.020	.007	-.004	.013	.002	.008	.005	.008	.006	.008	.007	.008	.007 2/	.008
Average	.007	.002	.011	.004	-.066	.019	-.017	.015	-.003	.013	.004	.012	.007	.012	.008	.013	.010	.013	.011	.013
HIGH-ALKALI CEMENT AND REPUBLIC																				
1	.014	.003	.038	.003	-.041	.006	.019	.004	.034	.008	.042	.010	.056	.030	.071	.048	.090	.069	.109	.086
1/ 2	.009	.005	.033	.005	-.047	.008	.017	.009	.031	.007	.042	.006	.063	.021	.084	.030	.111	.041	.140	.043
3	.010	.001	.032	.003	-.051	.003	.011	.002	.028	.004	.038	.005	.053	.009	.074	.019	.101	.036	.133	.050
4	.005	.008	.023	.008	-.062	.008	-.005	.012	.008	.010	.022	.010	.044	.008	.070	.011	.112	.026	.151	.037
5	.010	.004	.031	.005	-.050	.003	.015	.004	.029	.010	.045	.016	.075	.038	.122	.063	.183	.092	.241	.111
6																				
4/ Average	.010	.009	.031	.015	-.050	.021	.011	.024	.026	.026	.038	.023	.058	.031	.084	.052	.119	.093	.155	.132
MEDIUM-ALKALI CEMENT AND REPUBLIC																				
1	.010	.004	.020	.005	-.043	.005	.001	.005	.013	.016	.028	.010	.044	.015	.056	.018	.068	.022	.078	.024
1/ 2	.005	.004	.017	.005	-.049	.009	-.004	.005	.011	.012	.026	.014	.044	.018	.057	.021	.071	.023	.083	.029
3	.007	.002	.017	.003	-.050	.005	-.006	.005	.011	.003	.032	.004	.056	.012	.076	.018	.096	.024	.115	.030
4	.004	.004	.013	.004	-.056	.005	-.015	.004	.002	.008	.036	.013	.076	.019	.110	.025	.148	.032	.175	.037
5	.004	.003	.018	.004	-.050	.002	.002	.003	.012	.003	.029	.004	.048	.005	.061	.009	.078	.013	.093	.016
6																				
4/ Average	.006	.006	.017	.007	-.050	.013	-.004	.017	.010	.011	.030	.010	.054	.032	.072	.054	.092	.080	.109	.097
LOW-ALKALI CEMENT AND REPUBLICA																				
1	.010	.003	.017	.003	-.046	.003	.000	.004	.013	.003	.051	.003	.106	.008	.161	.012	.215	.017	.259	.022
1/ 2	.005	.002	.014	.003	-.046	.007	-.001	.006	.013	.004	.043	.029	.086	.054	.125	.086	.163	.122	.195	.177
3	.004	.002	.012	.002	-.053	.003	-.008	.001	.009	.005	.051	.007	.105	.019	.166	.028	.209	.044	.306	.166
4	.004	.003	.012	.007	-.055	.007	-.013	.005	.004	.004	.043	.005	.092	.015	.136	.026	.181	.033	.210	.036
5	.005	.002	.018	.002	-.047	.004	.001	.003	.017	.003	.056	.003	.111	.018	.160	.039	.201	.056	.238	.065
6																				
4/ Average	.006	.006	.015	.006	-.049	.009	-.004	.014	.011	.013	.049	.013	.100	.025	.150	.041	.194	.052	.242	.111

1/ Expansion at 44, 45, 51, 72, 100, 128, 156, 184, and 212 days were obtained by interpolation; percentage range readings were taken from series of readings closes
2/ Data obtained by interpolation.
3/ The range in percentage expansion is given for each group of specimens for every laboratory, and the last figure in the column is the range in the averages shown
4/ Average for five laboratories. The aggregate used as sand by Laboratory No. 6 was supplemented by crushing a sample of Republican River gravel and so is not the

PLATE I
PROCEEDINGS, AM. SOC. TESTING MATS.
VOL. 54
REPORT OF COMMITTEE C-9
POTENTIAL REACTIVITY
OF AGGREGATE IN CONCRETE

MENT-AGGREGATE COMBINATIONS SUBJECTED TO VARIATIONS OF TEMPERATURE AND WATER SATURATION (CONROW TEST)
ASTM Committee C-9
e corresponding to test age in days
)--expansion (percent)

	212		240		268		296		324		352		380		408		436		464	
Range	Expansion (percent)	Range	Expansion (percent)	Range	Expansion (percent)	Range	Expansion (percent)	Range	Expansion (percent)	Range	Expansion (percent)	Range	Expansion (percent)	Range	Expansion (percent)	Range	Expansion (percent)	Range	Expansion (percent)	Range
RAND COULEE AGGREGATE																				
0.010	0.008	0.010	0.008	0.011	0.008	0.010	0.008	0.012	0.008	0.010	0.008	0.009	0.009	0.009	0.013	0.009	0.015	0.008	0.015	0.010
.005	.014	.005	.014	.006	.014	.006	.015	.005	.015	.005	.015	.004	.016	.006	.016	.006	.016	.006	.014	.004
.001	.006	.001	.007	.002	.007	.002	.008	.002	.008	.001	.007	.001	.008	.003	.009	.002				
.010	.000	.009	.001	.012	.003	.016	.001	.008	-.001	.004	-.001	.006	.001	.004	.002	.007				
.002	.009	.006	.010	.004	.009	.003	.010	.004	.013	.004	.012	.002	.007	.006	.008	.005				
.004	.005	.006	.005	.007	.005	.007	.006	.007	.006	.007	.007	.008	.007	.008						
.012	.007	.014	.008	.013	.008	.011	.008	.014	.008	.016	.008	.016	.008	.015						
RAND COULEE AGGREGATE																				
.004	.002	.004	.002	.003	.003	.004	.003	.002	.003	.003	.003	.003	.003	.002	.007	.003	.009	.003	.009	.002
.003	.005	.002	.007	.002	.007	.002	.007	.002	.007	.001	.008	.003	.008	.004	.008	.003	.008	.003	.007	.003
.001	.003	.000	.003	.001	.004	.002	.004	.002	.004	.002	.005	.002	.004	.002	.004	.002	-	-	.004	.003
.008	-.002	.011	-.003	.007	-.001	.006	-.001	.006	-.003	.006	-.004	.006	-.003	.007	-.001	.007				
.003	.006	.004	.006	.003	.006	.001	.007	.003	.009	.005	.009	.004	.003	.003	.003	.004				
.003	.000	.003	.001	.005	.001	.005	.001	.004	.002	.003	.003	.004	.003	.004						
.006	.002	.008	.003	.010	.003	.008	.004	.008	.004	.012	.004	.013	.003	.011						
AND COULEE AGGREGATE																				
.002	.003	.003	.003	.003	.003	.003	.003	.003	.003	.002	.003	.003	.003	.003	.006	.005	.009	.002	.008	.003
.003	.005	.003	.006	.005	.007	.004	.006	.004	.006	.006	.007	.004	.007	.003	.007	.004	.007	.004	.005	.004
.002	.001	.003	.001	.002	.001	.003	.001	.002	.002	.002	.002	.002	.003	.002	.002	.002	-	-	.002	.002
.005	-.002	.004	-.001	.006	.000	.004	.000	.004	-.002	.003	-.002	.004	-.002	.003	-.001	.002				
.002	.006	.003	.008	.003	.007	.003	.008	.002	.007	.006	.009	.003	.003	.001	.005	.001				
.006	.002	.003	.002	.003	.002	.003	.003	.004	.003	.003	.004	.004	.003	.003						
.006	.002	.008	.003	.009	.003	.007	.004	.006	.003	.009	.004	.011	.003	.009						
EAR CREEK AGGREGATE																				
.005	.014	.005	.015	.005	.016	.005	.015	.003	.017	.005	.017	.005	.018	.005	.022	.007	.025	.005	.025	.005
.002	.018	.002	.019	.003	.020	.001	.019	.002	.020	.002	.021	.002	.021	.002	.022	.003	.020	.004	.020	.003
.002	.011	.001	.012	.003	.013	.001	.014	.001	.014	.002	.015	.002	.016	.001	.016	.003				
.005	.007	.004	.008	.007	.008	.006	.008	.004	.008	.005	.008	.005	.008	.005	.012	.005				
.003	.017	.004	.017	.005	.018	.003	.019	.006	.019	.005	.021	.006	.023	.006	.023	.027				
.007	.009	.008	.010	.006	.011	.006	.011	.006	.012	.003	.013	.006	.013	.006						
.009	.013	.011	.014	.011	.014	.012	.014	.011	.015	.012	.016	.013	.016	.015						
LEAR CREEK AGGREGATE																				
.006	.009	.006	.010	.007	.010	.007	.011	.007	.011	.006	.010	.005	.011	.006	.016	.006	.018	.005	.018	.004
.007	.013	.007	.014	.007	.014	.006	.014	.006	.015	.007	.015	.007	.016	.006	.016	.008	.015	.008	.015	.009
.004	.013	.004	.013	.003	.014	.004	.014	.004	.014	.004	.014	.002	.016	.004	.016	.002	.015	.003	.016	.003
.008	.015	.007	.016	.006	.016	.006	.017	.006	.017	.006	.017	.009	.018	.005	.021	.007				
.004	.021	.007	.021	.005	.023	.005	.022	.005	.022	.005	.025	.004	.026	.006	.022	.012				
.007	.012	.009	.013	.009	.013	.009	.013	.009	.014	.008	.015	.009	.015	.009						
.011	.014	.012	.014	.011	.015	.013	.015	.011	.016	.011	.016	.015	.017	.015						
EAR CREEK AGGREGATE																				
.004	.012	.004	.012	.005	.013	.004	.013	.005	.013	.004	.013	.004	.014	.005	.018	.006	.022	.004	.022	.004
.003	.018	.004	.018	.003	.019	.004	.018	.004	.019	.005	.019	.004	.019	.004	.020	.004	.019	.004	.018	.005
.003	.010	.004	.010	.004	.010	.005	.010	.003	.011	.004	.011	.004	.012	.004	.012	-	.011	-	.011	.003
.006	.004	.006	.004	.006	.004	.006	.004	.006	.004	.006	.004	.007	.004	.005	.006	.004				
.006	.019	.006	.020	.005	.018	.006	.019	.004	.020	.005	.020	.006	.021	.008	.016	.003				
.008	.008	.008	.008	.009	.008	.009	.008	.009	.009	.010	.010	.010	.009	.010						
.013	.012	.015	.012	.015	.012	.015	.012	.015	.013	.016	.013	.016	.013	.017						
PUBLICAN RIVER AGGREGATE																				
.086	.131	.103	.150	.119	.167	.132	.185	.141	.199	.145	.208	.150	.216	.154	.220	.156	.227	.158	.231	.159
.043	.169	.048	.197	.049	.222	.047	.241	.042	.262	.039	.276	.038	.287	.035	.296	.033	.302	.034	.309	.032
.050	.163	.057	.197	.068	.227	.088	.253	.087	.273	.087	.289	.093	.302	.097	.313	.098	.321	.101	.328	.098
.037	.189	.043	.220	.045	.243	.048	.262	.048	.278	.047	.288	.048	.300	.048	.307	.049				
.111	.299	.128	.342	.145	.377	.137	.403	.139	.423	.138	.442	.139	.451	.133	.455	.132				
.132	.190	.168	.221	.192	.247	.210	.269	.218	.287	.224	.301	.234	.311	.235	.318	.235				
PUBLICAN RIVER AGGREGATE																				
.024	.086	.027	.094	.028	.098	.030	.107	.032	.114	.034	.116	.034	.120	.037	.121	.036	.125	.037	.127	.037
.029	.094	.031	.103	.036	.111	.038	.116	.040	.124	.045	.130	.045	.135	.048	.140	.047	.141	.049	.143	.049
.030	.128	.035	.143	.041	.156	.047	.165	.051	.175	.053	.181	.055	.188	.057	.193	.060	.196	.062	.200	.061
.037	.196	.039	.213	.041	.226	.042	.236	.042	.244	.042	.252	.042	.259	.042	.264	.042				
.016	.109	.010	.118	.013	.129	.013	-	-	.143	.015	.152	.016	.153	.018	.158	.020				
.097	.123	.110	.134	.119	.144	.128	-	-	.160	.130	.166	.136	.171	.139	.175	.143				
UBLICAN RIVER AGGREGATE																				
.022	.294	.020	.321	.022	.341	.024	.360	.025	.374	.023	.383	.022	.392	.020	.396	.021	.404	.021	.409	.021
.177	.217	.189	.235	.203	.249	.207	.257	.212	.270	.215	.277	.214	.283	.219	.289	.219	.293	.220	.296	.219
.166	.333	.161	.355	.163	.366	.170	.384	.168	.394	.170	.403	.169	.410	.171	-	-	.419	.167	.423	.168
.036	.231	.035	.248	.032	.261	.032	.270	.031	.277	.031	.283	.034	.291	.034	.296	.033				
.065	.262	.068	.281	.071	.295	.073	.305	.075	.317	.075	.329	.074	.334	.073	.341	.074				
.111	.267	.116	.288	.120	.302	.117	.315	.127	.326	.124	.335	.126	.342	.127	-	-				

losest to date shown.

shown in the column to the left.
t the same as that used by the other laboratories.

rhyolites, latites, and chalcedonic cherts. The particles of the sand are predominantly angular to subangular.

Sand and Gravel, Republican River near St. Francis, Kans.—The gravel from the Republican River near St. Francis, Kans., is composed mainly of granites, quartz, potassium feldspars, and acidic to intermediate volcanic rocks. Small proportions of cherts, quartzites, limestones, basalts, sandy chalks, and ferruginous material also are present. The pebbles are predominantly subangular to subround.

Coarse grained pink granite and individual grains of pink potassium feldspars constitute approximately 56.7 per cent of the gravel and are considered from a physical standpoint to be unsound. These granites and feldspars are characterized by a very low linear thermal coefficient of expansion. They are hard and predominantly unaffected by weathering. The particles are subangular to subround in shape with smooth surfaces; they are not porous and are essentially impermeable. Consequently, it is to be anticipated that these particles would contribute to deterioration of concrete subjected to volume change through wetting and drying and heating and cooling because of (1) low thermal coefficient of expansion, (2) poor bond with cement, and (3) rigidity of the particles, which would tend to increase tensile stress in contracting cement paste. About 2.9 per cent of the sample is composed of absorptive and friable chalk particles and ferruginous material. These rock types are also classified as physically unsound.

Rhyolites, andesites, cherts, and opal-bearing sandy chalks are considered to be potentially deleteriously reactive with cement alkalies; they constitute an average of 11.7 per cent of the three size fractions of the gravel.

The coarse fractions of the Republican River sand are composed chiefly of quartz and potassium feldspars, but they contain a small proportion of the rock types observed in the related gravels. The finer fractions are composed predominantly of quartz; moderate amounts of potassium feldspars and small proportions of opal-bearing sandy chalks, rhyolites, andesites, chalcedonic cherts, magnetite, and acidic volcanic glass

TABLE III.—REPRODUCIBILITY OF THE PROPOSED TENTATIVE METHOD OF TEST FOR POTENTIAL VOLUME CHANGE OF CEMENT-AGGREGATE COMBINATIONS.[a]

Cement		Aggregate	Average Expansion for Cooperating Laboratories, per cent	Maximum Range in Expansion Within Batches, per cent			Range in Expansion Between Batches Within the Laboratories, per cent			Range in Average Expansion Between the Laboratories, per cent		
	Alkali Content, per cent (Na_2O equivalent)			Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average
No. 7488	1.19	Grand Coulee Dam, Wash.	0.008	0.008	0.001	0.004	0.009	0.003	0.006	0.015	0.000	0.006
No. 2448	0.58		0.003	0.005	0.000	0.002	0.007	0.002	0.004	0.011	0.000	0.004
No. 9406	0.17		0.003	0.004	0.000	0.001	0.003	0.001	0.003	0.009	0.000	0.003
No. 7488	1.19	Clear Creek, near Denver, Colo.	0.016	0.006	0.000	0.003	0.006	0.001	0.004	0.015	0.002	0.005
No. 2448	0.58		0.017	0.006	0.001	0.003	0.009	0.004	0.006	0.015	0.000	0.006
No. 9406	0.17		0.013	0.008	0.001	0.004	0.010	0.004	0.006	0.017	0.002	0.006
No. 7488	1.19	Republican River, near St. Francis, Kans.	0.311	0.106	0.029	0.061	0.154	0.035	0.093	0.235	0.002	0.097
No. 2448	0.58		0.171	0.031	0.005	0.018	0.057	0.018	0.040	0.139	0.015	0.066
No. 9406	0.17		0.342	0.058	0.010	0.027	0.219	0.020	0.103	0.127	0.008	0.071

[a] Based on results at an age of 380 days.

are present. The fraction passing the No. 100 sieve contains 3.5 per cent of opaline diatom skeletons and 2.6 per cent of acidic volcanic glass. The particles in all fractions range from subround to angular.

Potassium feldspars constitute 19.5 per cent of the sand. As mentioned above, particles composed of individual crystals of potassium feldspars are considered to be physically unsound. Rhyolites, andesites, chalcedonic cherts, opal-bearing sandy chalks, acidic volcanic glass, and opaline skeletons of diatoms constitute 3.7 per cent of the sand; these particles are considered to be potentially deleteriously reactive with cement alkalies.

Aggregate for the Conrow Test:

Aggregate for the Conrow test was prepared as follows for each participating laboratory:

Material	Source	Remarks
Natural sand	Clear Creek near Denver, Colo.	Supplied in twelve 1125-g batches containing equal parts by weight of the No. 4–8, 8–16, 16–30, 30–50, and 50–100 fractions and 5 per cent minus No. 100 fraction; samples were dried to constant weight at 130 F and packaged individually in sealed metal cans.
Natural sand	Republican River near St. Francis, Kans.	Supplied as ungraded sand and gravel; detailed instructions were supplied on sieving and drying so as to prepare batches as for Clear Creek sand.
Crushed gravel	Columbia River near Coulee City, Wash.	Batches supplied as described for the Clear Creek sand, except that no material passing the No. 100 sieve was included.

Aggregate for the Scholer Test:

Aggregate for the Scholer test was prepared as follows for each participating laboratory:

Material	Source	Remarks
Natural sand and gravel	Clear Creek near Denver, Colo.	Supplied to each laboratory in six 60-lb batches; samples were dried to constant weight at 130 F and packaged in sealed metal cans.
Natural sand and gravel	Columbia River near Coulee City, Wash.	Same as above.
Natural sand and gravel	Republican River near St. Francis, Kans.	Supplied as ungraded sand and gravel; detailed instructions were supplied on sieving and drying so as to prepare batches as for the Clear Creek and Columbia River aggregates.

Each batch of aggregate contained 50 per cent by weight of fine aggregate and 50 per cent of coarse aggregate in the following gradation:

Size Fraction	Per cent by Weight
Coarse aggregate:	
$\frac{3}{8}$ to $\frac{3}{4}$ in.	60
$\frac{3}{16}$ to $\frac{3}{8}$ in.	40
Fine aggregate:	
No. 4–8	15
No. 8–16	15
No. 16–30	25
No. 30–50	24
No. 50–100	16
Minus No. 100	5

TEST PROCEDURE

Proposed Tentative Method of Test for Potential Volume Change of Cement-Aggregate Combinations (Conrow Test):

For the Conrow test all details of the proposed Tentative Method of Test for Potential Volume Change of Cement-Aggregate Combinations[2] were followed, using the cements and aggregates described above and mix data supplied by the Bureau of Reclamation.[5] The program at each cooperating laboratory comprised two batches for each of nine cement-aggregate combinations, a total of 18 batches or 54 specimens.

Briefly, the Conrow test employs 1 by 1 by 11¼-in. mortar bars containing 1 part portland cement to 2.25 parts graded fine aggregate by weight. Mixing water is adjusted to achieve a stipulated flow. Following mixing, the specimens are stored in a moist closet or moist room at 73.4 ± 3.0 F for 24 hr. They are then placed in metal containers which are immersed in water at 73.4 ± 3.0 F for 24 hr. Following this treatment, the reference length of the specimens is measured. The specimens are returned to the same containers and are again immersed

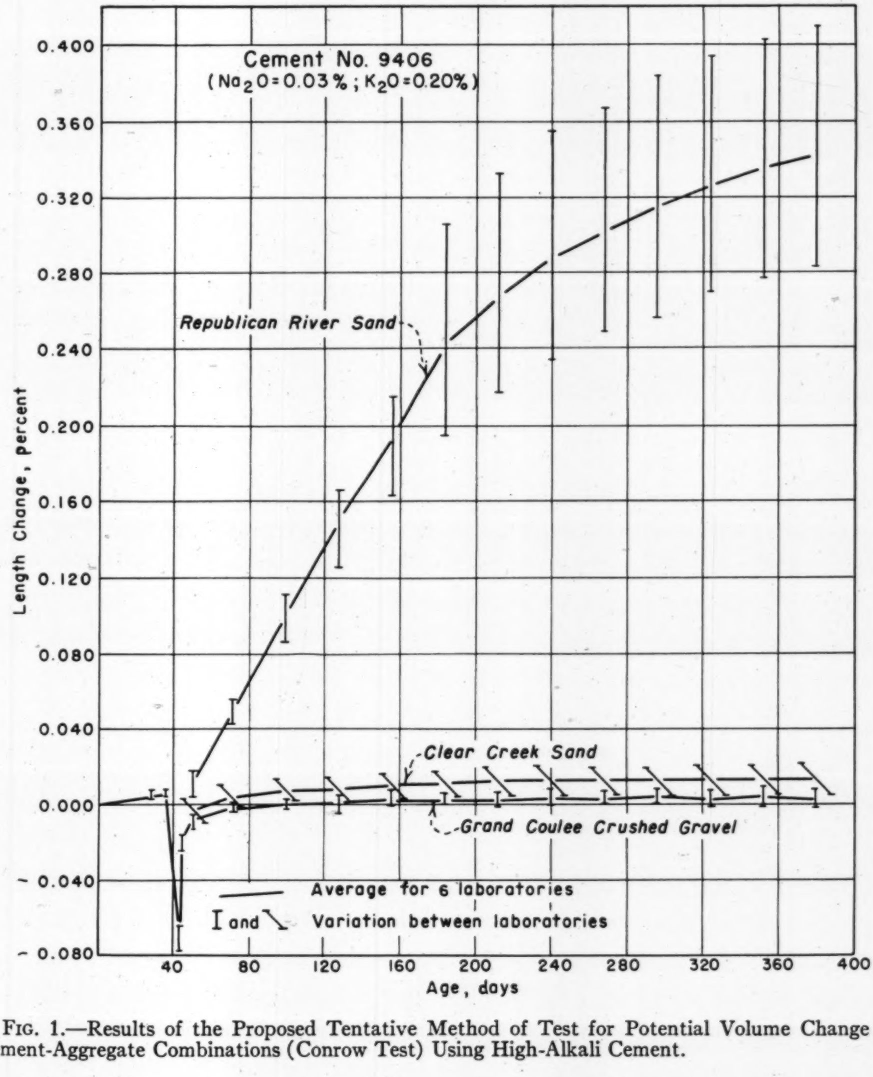

FIG. 1.—Results of the Proposed Tentative Method of Test for Potential Volume Change of Cement-Aggregate Combinations (Conrow Test) Using High-Alkali Cement.

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[5] Except for one laboratory which depleted its supply of Republican River sand and so supplemented the natural sand with fine aggregate obtained by crushing of the gravel.

in the same water at 73.4 ± 3.0 F until they have attained an age of 28 days. The containers holding the water and the specimens are stored at 131 ± 3 F for 7 days, then cooled to 73.4 ± 3.0 F for 24 hr. The specimens are removed from the containers and stored at 131 ± 3 F for 7 days in an oven. The specimens then are returned to their respective containers and water and stored at 73.4 ± 3.0 F.

Length change is determined at intervals of 28 days thereafter.

Proposed Tentative Method of Test for Potential Abnormal Expansion of Cement-Aggregate Combinations (Scholer Test):

For the Scholer test all details of the proposed Method of Test for Potential Abnormal Expansion of Cement-Aggregate Combinations were followed using the cements and aggregates as described above and mix data supplied by the Bureau of Reclamation. The procedure included nine cement-aggregate combinations, a total of 27 specimens, at each cooperating laboratory.

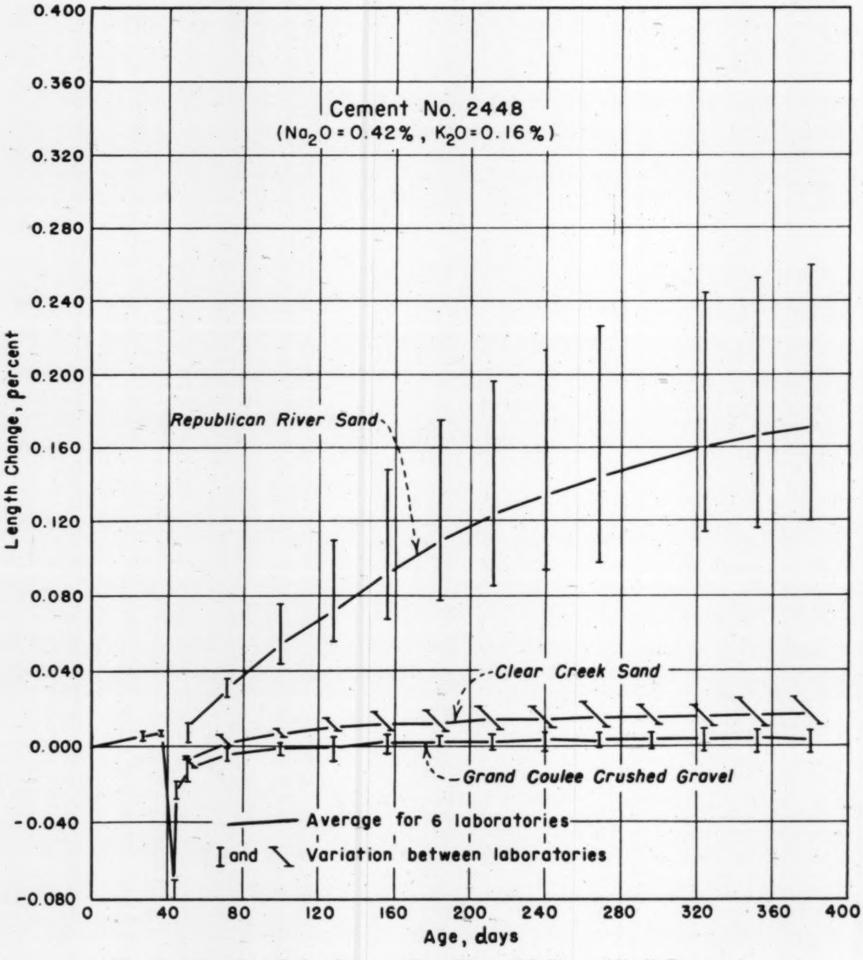

FIG. 2.—Results of the Conrow Test Using Medium-Alkali Cement.

The test procedure may be summarized as follows:

The test employs 3 by 4 by 16-in. concrete beams containing the same mix parts as are to be used in construction. Following mixing, the specimens are stored for 24 hr at 65 to 75 F covered by wet burlap; then in a moist condition at 73.4 ± 3.0 F until they are 7 days old; then at 73.4 ± 3.0 F at 50 ± 5 per cent relative humidity until they are 28 days old; and then in water at 73.4 ± 3.0 F until they are 30 days old.

After an age of 30 days, the specimens are subjected to a daily cycle of alternate heating-drying at 130 ± 3 F for 8 hr and cooling-soaking at 70 to 80 F for 16 hr.

Length change at the end of each 20 cycles of heating-drying and cooling-soaking is referred to length of the specimens at an age of 24 hr.

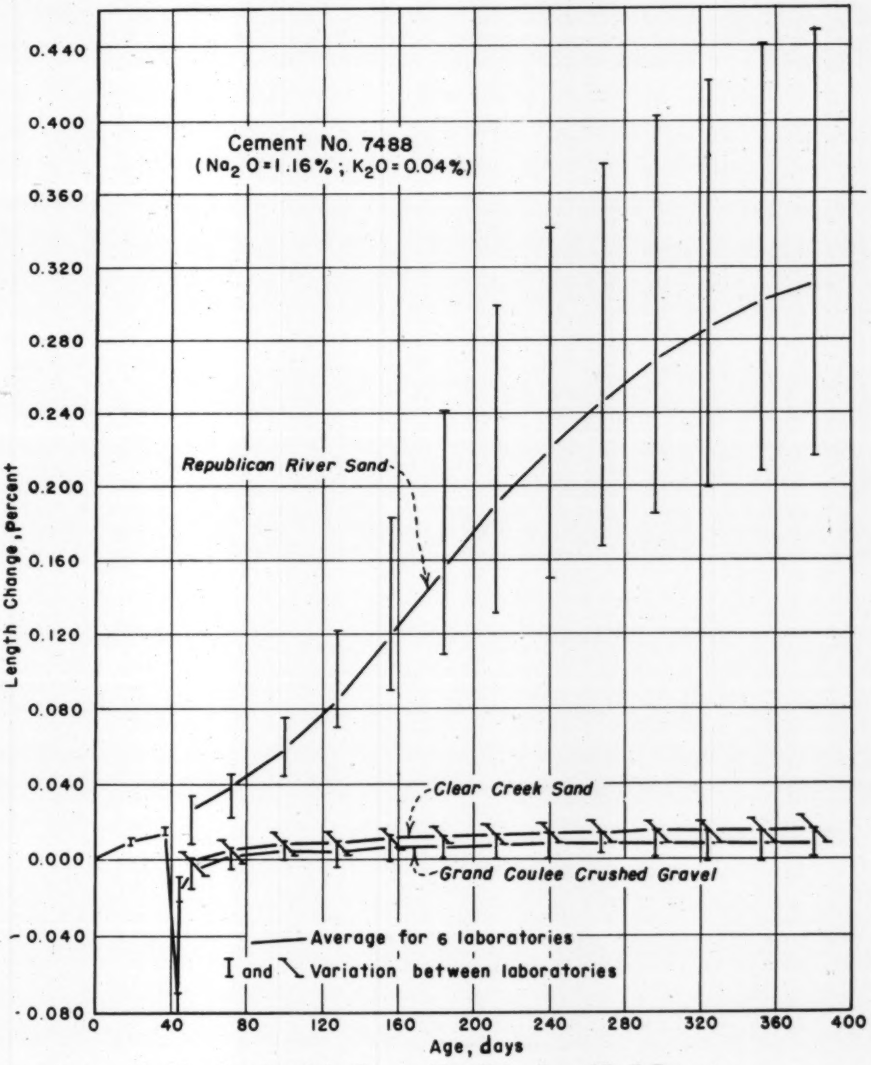

FIG. 3.—Results of the Conrow Test Using Low-Alkali Cement.

RESULTS OF THE TESTS

Conrow Test:

Significant expansion was obtained only in combinations containing the Republican River aggregate, but this aggregate caused large expansion regardless of the cement used (Table II (Plate I) and Figs. 1, 2, and 3). Greatest expansion was obtained on specimens containing the cement of lowest alkali content; least expansion was obtained with the low-alkali cement of intermediate alkali content (No. 2448). At an age of 380 days the average expansion of specimens containing Columbia River aggregate ranged from 0.003 to 0.008 per cent, and the average expansion of specimens containing Clear Creek aggregate ranged from 0.013 to 0.017 per cent.

Rapid expansion of the specimens containing the Republican River aggregate began immediately after storage at a constant temperature of 73.4 ± 3.0 F, the average for five laboratories being 0.342 per cent with the very low-alkali cement and 0.171 per cent with the cement of intermediate alkali content (No. 2448) at an age of 380 days. By an error, one cooperating laboratory depleted its supply of Republican River sand for the Conrow test and so supplemented the natural sand with fine aggregate produced by crushing of the gravel. For these mixes, expansion of the specimens containing the very low-alkali cement was reduced to less than one tenth the average expansion obtained by the other five laboratories with the same cement and the natural sand. The average expansion of specimens containing the high-alkali cement was reduced about 54 per cent and that of the specimens containing the cement of intermediate alkali content (No. 2448) about 85 per cent by this substitution of crushed fine aggregate for natural sand.[6] These data are not included in the analysis of reproducibility of the method.

Reproducibility of the test is considered satisfactory both within laboratories and between laboratories (Table III and Figs. 1, 2, and 3). For specimens containing Columbia River crushed gravel or Clear Creek sand, the maximum range in expansion between batches of specimens in any laboratory is 0.010 per cent, the average being 0.005 per cent at an age of 380 days. The maximum range in expansion of specimens from the same batch is 0.008 per cent, the average being 0.003 per cent. For these same combinations the maximum range in average expansion between the laboratories is 0.017 per cent, the average being 0.005 per cent.

Reproducibility is less good for the combinations containing Republican River aggregate because expansion develops to great magnitude and the specimens are disrupted by random fractures. The maximum range in expansion between specimens from different batches in any laboratory is 0.219 per cent, the average being 0.079 per cent at an age of 380 days. The maximum range in expansion of specimens from the same batch is 0.106 per cent, the average being 0.035 per cent. The maximum range in average expansion between the laboratories is 0.235 per cent, the average being 0.078 per cent. It will be recognized that the divergence in results obtained for specimens containing Republican River aggregate is of little significance in evaluation of the test because any limit placed on permissible expansion in the test inevitably will be much less than the expansion attained at 380 days by most of these combinations.

Scholer Test:

Significant expansion was obtained consistently only with combinations containing Republican River aggregate and the high-alkali cement or the low-alkali cement of intermediate alkali content (No. 2448) (Table IV (Plate II) and Figs. 4 and 5). After 200 cycles of heating-drying and cooling-soaking, the average expansion of specimens containing Columbia River aggregate or Clear Creek aggregate ranges from −0.003 to 0.008 per cent. Laboratory No. 3 (Table IV) reported inordinate expansion in this test for one specimen of the three representing the combination of Clear Creek aggregate and the very low-alkali cement. After 200 cycles two cracks were evident at the end of the specimen, and the expansion was found to be 0.056 per cent in

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[6] The observed great change in results of the test with processing of the aggregate is believed to bear significantly upon the performance of concrete in structures, particularly in the interpretation of widely varying performance of apparently similar concrete.

TABLE IV--SUMMARY OF RESULTS OF COOPERATIVE TESTS--PROPOSED TENTATIVE METHOD OF TEST

Subcommittee II-

Cooperating Laboratory	Curing period to age shown (days)																				
	7--Fog 1/		28--50% RH		30--H_2O		20		40		60		80		100		120		140		16
	Expansion: (percent)	3/ Range	Expansion: (percent)	Range	Expansion: (percent)	Range	Expansion: (percent)	Range	Expansion: (percent)	Range	Expansion: (percent)	Range	Expansion: (percent)	Range	Expansion: (percent)	Range	Expansion: (percent)	Range	Expansion: (percent)	Range	Expansion (percent)
HIGH-ALKALI CEMENT A																					
1	0.006	0.001	-0.038	0.004	-0.013	0.001	-0.004	0.002	0.000	0.004	0.003	0.006	0.003	0.009	0.002	0.010	0.017	0.012	0.007	0.015	0.008
2	.012	.005	-.032	.004	-.011	.002	-.055	.002	.007	.008	.011	.001	.009	.001	.008	.003	.011	.001	.010	.005	.013
3	.001	.002	-.040	.002	-.018	.002	-.001	.003	.001	.003	.002	.004	.000	.002	.006	.004	.004	.004	.004	.005	.002
4	2/ -	-	-.031	.004	-.007	.000	.005	.007	-.005	.007	-.002	.007	-.002	.007	.007	.013	.000	.014	.000	.014	.005
5	.000	.000	-.042	.004	-.017	.000	-.001	.000	-.008	.002	-.001	.004	.000	.009	.002	.009	.000	.013	.001	.016	.001
6	.004	.000	-.041	.001	-.015	.002	-.003	.000	-.002	.001	-.001	.001	-.001	.001	-.003	.002	.000	.007	-.004	.006	-.003
Average	.005	.012	-.037	.011	-.014	.011	-.010	.060	-.001	.015	.002	.013	.002	.011	.004	.011	.005	.017	.003	.014	.004
MEDIUM-ALKALI CEMENT																					
1	.004	.001	-.039	.003	-.014	.002	-.007	.001	-.003	.003	-.003	.004	-.003	.002	-.005	.003	-.003	.003	-.003	.003	-.002
2	.007	.004	-.031	.002	-.010	.004	-.060	.004	-.001	.004	.007	.008	.004	.004	.003	.003	.003	.009	.007	.008	.006
3	.003	.001	-.037	.005	-.014	.002	-.001	.004	.000	.005	.000	.004	.003	.004	.004	.004	.004	.004	.000	.007	-.003
4	-	-	-.027	.000	-.009	.006	-.007	.000	-.007	.000	-.013	.000	-.011	.006	-.015	.007	-.009	.006	-.009	.013	-.009
5	.000	.002	-.037	.005	-.016	.004	-.004	.002	-.010	.002	-.006	.002	-.005	.003	-.007	.001	-.007	.000	-.009	.004	-.008
6	.004	.001	-.040	.002	-.011	.000	-.004	.000	-.004	.000	-.003	.001	-.004	.000	-.004	.001	-.004	.000	-.005	.002	-.005
Average	.004	.007	-.035	.013	-.012	.007	-.014	.059	-.004	.010	-.003	.020	-.003	.016	-.004	.019	-.003	.013	-.003	.016	-.004
LOW-ALKALI CEMENT A																					
1	.004	.001	-.025	.001	-.006	.002	-.005	.000	-.001	.001	.001	.000	-.001	.001	-.002	.002	.001	.002	-.001	.000	.000
2	.009	.004	-.022	.003	-.005	.001	-.057	.006	.005	.006	.010	.005	.010	.009	.009	.004	.010	.008	.011	.008	.011
3	.002	.000	-.027	.001	-.009	.000	-.001	.002	.002	.003	.002	.004	.006	.004	.007	.004	.005	.004	.004	.004	.003
4	-	-	-.025	.007	-.005	.007	.000	.000	-.002	.007	-.007	.000	-.011	.006	-.011	.006	-.002	.007	-.011	.006	-.002
5	.002	.001	-.026	.001	-.008	.001	.000	.002	-.002	.001	.001	.002	.002	.003	.000	.001	-.001	.002	-.003	.003	-.003
6	.004	.000	-.030	.001	-.006	.001	-.002	.001	-.001	.001	-.001	.001	-.002	.002	-.001	.001	-.001	.000	.000	.001	-.001
Average	.004	.007	-.026	.008	-.006	.004	-.011	.057	.000	.007	.001	.017	.001	.021	.000	.020	.002	.012	.000	.022	.001
HIGH-ALKALI CEMENT A																					
1	.005	.001	-.043	.001	-.017	.002	-.005	.001	-.001	.002	.004	.002	.003	.002	.000	.004	.004	.002	.003	.003	.005
2	.015	.007	-.041	.009	-.007	.009	-.049	.010	.010	.015	.017	.007	.016	.005	.014	.009	.017	.005	.018	.008	.017
3	.002	.001	-.044	.001	-.019	.001	.003	.001	.005	.000	.004	.001	.005	.001	.011	.002	.015	.002	.014	.002	.017
4	--	-	-.033	.000	-.011	.006	.002	.007	-.002	.007	-.007	.000	.000	.000	-.007	.000	.002	.007	-.002	.007	.005
5	.003	.003	-.043	.003	-.020	.004	.001	.001	-.004	.003	-.002	.003	.001	.006	.000	.002	-.003	.001	-.005	.004	-.003
6	.006	.001	-.045	.001	-.016	.000	.000	.001	.002	.001	.004	.000	.004	.000	.002	.001	.006	.001	.002	.001	.004
Average	.006	.013	-.042	.012	-.015	.013	-.009	.052	.002	.014	.003	.024	.005	.016	.003	.021	.007	.020	.005	.023	.008
MEDIUM-ALKALI CEMENT A																					
1	.003	.001	-.050	.002	-.018	.002	-.010	.002	-.009	.001	-.005	.005	-.008	.002	-.010	.003	-.007	.003	-.009	.001	-.005
2	.012	.002	-.033	.018	-.005	.003	-.057	.002	.009	.004	.010	.002	.009	.002	.006	.002	.009	.001	.010	.001	.011
3	.003	.001	-.046	.002	-.016	.002	-.004	.002	-.003	.004	-.002	.004	-.004	.002	.000	.003	-.002	.004	.002	.006	-.003
4	-	-	-.035	.007	-.002	.007	-.004	.013	.007	.000	.005	.007	-.002	.007	.000	.000	.002	.007	.005	.007	.002
5	.000	.001	-.040	.004	-.015	.001	-.002	.009	-.003	.003	-.004	.003	-.004	.002	-.003	.010	-.006	.005	-.008	.010	-.006
6	.005	.001	-.049	.002	-.014	.001	-.005	.001	-.005	.002	-.005	.001	-.005	.001	-.006	.000	-.006	.000	-.007	.002	-.007
Average	.005	.012	-.042	.017	-.012	.016	-.014	.055	-.001	.018	.000	.015	-.002	.017	-.002	.016	-.002	.016	-.001	.019	-.001
LOW-ALKALI CEMENT AN																					
1	.003	.000	-.033	.003	-.011	.003	-.007	.001	-.003	.001	-.001	.002	-.001	.003	-.004	.002	-.002	.003	-.003	.001	-.001
2	.010	.005	-.031	.002	-.004	.007	-.055	.008	.011	.008	.012	.009	.012	.008	.009	.006	.011	.007	.012	.005	.012
3	.003	.001	-.032	.000	-.010	.001	-.002	.001	-.001	.000	-.002	.002	.000	.003	.004	.006	.006	.008	.009	.012	.013
4	-	-	-.025	.007	.002	.007	-.002	.007	.009	.006	.007	.006	.000	.000	.000	.000	.002	.007	.002	.007	.000
5	.000	.001	-.032	.003	-.012	.001	-.004	.002	-.002	.001	.000	.001	-.001	.003	-.004	.008	-.001	.001	-.001	.003	.002
6	.004	.000	-.036	.002	-.010	.000	-.004	.001	-.002	.001	-.002	.001	-.001	.001	-.002	.001	-.002	.007	-.002	.005	-.003
Average	.004	.010	-.032	.011	-.008	.014	-.012	.053	.002	.014	.002	.014	.002	.013	.000	.013	.002	.013	.003	.015	.003
HIGH-ALKALI CEMENT AND																					
1	.000	.002	-.032	.002	-.016	.002	.014	.003	.026	.006	.044	.011	.083	.025	.122	.032	.170	.037	.223	.046	.272
2	.004	.008	-.029	.014	-.012	.002	-.034	.008	.038	.015	.068	.060	.115	.136	.162	.170	.237	.186	.314	.180	.387
3	.001	.001	-.029	.002	-.012	.002	.047	.001	.086	.012	.131	.028	.189	.038	.258	.038	.340	.020	.423	.001	.493
4	-	-	-.029	.006	-.007	.013	.007	.027	.024	.013	.049	.013	.058	.007	.084	.020	.129	.027	.178	.033	.230
5	.007	.000	-.032	.002	-.024	.003	.018	.004	.037	.005	.031	.002	.048	.003	.036	.007	.103	.031	.148	.055	.191
6	.004	.000	-.034	.002	-.012	.001	.012	.003	.026	.014	.055	.022	.110	.041	.184	.060	.254	.075	.325	.072	.386
Average	.003	.007	-.031	.005	-.014	.017	.011	.081	.040	.062	.063	.100	.100	.141	.141	.222	.206	.237	.268	.275	.326
MEDIUM-ALKALI CEMENT AND																					
1	.000	.002	-.028	.001	-.013	.002	.000	.002	.003	.004	.002	.004	.010	.005	.014	.005	.017	.007	.021	.009	.019
2	.012	.008	-.021	.015	-.017	.013	-.035	.009	.025	.035	.033	.026	.033	.029	.030	.029	.035	.029	.034	.033	.035
3	.000	.000	-.035	.003	-.014	.003	.013	.006	.018	.006	.021	.004	.033	.006	.047	.018	.073	.041	.103	.062	.130
4	-	-	-.027	.000	.000	.000	.002	.007	.013	.000	.013	.013	.007	.000	.011	.006	.011	.006	.009	.006	.011
5	.000	.002	-.058	.009	-.016	.001	-.002	.002	.002	.003	.002	.002	-.002	.003	.000	.003	-.002	.005	-.001	.002	-.006
6	.004	.000	-.038	.001	-.011	.001	.000	.002	.000	.002	.000	.002	-.001	.001	-.001	.002	.000	.002	-.002	.002	-.001
Average	.003	.012	-.034	.037	-.012	.017	-.004	.048	.010	.025	.012	.033	.013	.035	.017	.048	.022	.075	.027	.105	.031
LOW-ALKALI CEMENT AND																					
1	.002	.006	-.035	.004	-.015	.005	-.003	.001	-.001	.000	.008	.004	.008	.003	.011	.004	.012	.004	.016	.005	.012
2	.006	.003	-.020	.004	-.024	.010	-.049	.006	.016	.004	.021	.003	.019	.005	.017	.004	.021	.001	.022	.002	.022
3	.001	.000	-.026	.001	-.010	.002	.010	.004	.018	.003	.022	.005	.031	.005	.032	.005	.040	.009	.046	.018	.046
4	-	-	-.025	.007	-.005	.007	.000	.000	.009	.006	.011	.020	.007	.013	.007	.013	.013	.013	.011	.006	.007
5	.002	.002	-.019	.007	-.004	.005	.004	.004	.004	.003	.006	.002	.006	.003	.007	.001	.008	.002	.013	.000	.003
6	.004	.000	-.027	.002	-.006	.001	-.001	.004	.000	.004	.000	.004	.000	.004	.000	.004	.000	.003	.001	.003	.000
Average	.003	.005	-.025	.016	.011	.020	-.006	.059	.008	.019	.010	.022	.012	.031	.012	.032	.016	.0040	.018	.045	.015

Fog = 100% percent relative humidity at 73° F ± 3.0° F, or burlap-covered at 65° F to 75° F; 50% RH = 50% ± 5% relative humidity at 73° F ± 3.0° F; H_2O = immersed in

Initial reading was taken at 7 days.

Range in expansion is given for each group of specimens prepared by each laboratory. The figure in the line designated "Average" is the range found in the averages

PLATE II
PROCEEDINGS, AM. SOC. TESTING MATS.
VOL. 54
REPORT OF COMMITTEE C-9
POTENTIAL REACTIVITY
OF AGGREGATE IN CONCRETE

TEST FOR POTENTIAL ABNORMAL EXPANSION OF CEMENT-AGGREGATE COMBINATIONS (SCHOLER TEST)
ee II-b, ASTM Committee C-9

Test period (cycles)																					
160		180		200		220		240		250		280		300		320		340		360	
ansion (rcent)	Range	Expansion (percent)	Range	Expansion (percent)	Range	Expansion (percent)	Range	Expansion (percent)	Range	Expansion (percent)	Range	Expansion (percent)	Range	Expansion (percent)	Range	Expansion (percent)	Range	Expansion (percent)	Range	Expansion (percent)	Range
MENT AND GRAND COULEE AGGREGATE																					
.008	0.017	0.011	0.017	0.011	0.015	0.013	0.015	0.010	0.017	0.010	0.015	0.007	0.017	0.007	0.015	0.009	0.016	0.010	0.014	0.007	0.015
.013	.001	.012	.002	.010	.006	.012	.004	.009	.005	.009	.004	.014	.004	.008	.001	.009	.008				
.002	.005	-.001	.005	.000	.006	-.002	.006	-.003	.007	-.006	.005	-.004	.008	-.008	.004						
.005	.007	.005	.007	.005	.007	.005	.007	.007	.013	.005	.007										
.001	.010	.003	.015	.003	.014	.002	.018	.003	.019	.003	.019	.003	.021	.007	.022	.007	.016				
.003	.007	-.004	.007	-.004	.007	-.003	.007	-.002	.006	-.001	.008	-.001	.007								
.004	.016	.004	.016	.004	.015	.004	.015	.004	.013	.003	.015										
EMENT AND GRAND COULEE AGGREGATE																					
.002	.003	.001	.004	.001	.005	.004	.006	.001	.004	.002	.003	-.003	.005	-.004	.003	-.002	.004	-.003	.004	-.004	.002
.006	.004	.006	.005	.001	.006	.003	.002	.003	.003	.004	.008	.007	.009	.004	.008	.006	.014				
.003	.007	-.007	.005	-.003	.004	-.005	.004	-.010	.007	-.008	.006	-.011	.007								
.009	.006	-.009	.006	-.005	.007	-.009	.006	-.002	.007	-.005	.007										
.008	.002	-.007	.005	-.008	.003	-.009	.004	-.007	.005	-.009	.003	-.010	.003	-.010	.005	-.008	.009	-.008	.004		
.005	.002	-.005	.002	-.005	.002	-.005	.002	-.005	.002	-.005	.002	-.005	.002								
.004	.015	-.004	.015	-.093	.009	-.004	.013	-.003	.013	-.004	.013										
MENT AND GRAND COULEE AGGREGATE																					
.000	.005	.003	.001	.003	.001	.005	.001	.002	.001	002	.002	.000	.002	-.002	.002	.000	.001	-.002	.002	-.002	.003
.011	.006	.014	.012	.009	.013	.011	.010	.008	.009	.011	.013	.013	.010	.011	.011	.008	.016				
.003	.004	.000	.006	-.001	.005	-.003	.005	-.004	.006	-.009	.007	-.013	.007								
.002	.007	-.007	.013	-.002	.007	-.005	.007	-.002	.014	-.085	.007										
.003	.002	-.003	.006	-.005	.000	-.002	.002	-.006	.003	-.003	.005	-.004	.005	.002	.004	-.002	.004				
.001	.001	-.001	.000	-.001	.000	-.001	.000	-.001	.000	-.001	.001	.000	.000								
.001	.014	.001	.021	.001	.014	.002	.016	.000	.014	-.001	.020										
MENT AND CLEAR CREEK AGGREGATE																					
.005	.002	.009	.003	.010	.002	.012	.004	.008	.003	.009	.003	.006	.003	.006	.002	.008	.002	.008	.003	.007	.003
.017	.007	.020	.007	.014	.005	.017	.010	.016	.008	.016	.008	.019	.007	.016	.004	.017	.011				
.017	.001	.015	.000	.013	.002	.014	.001	.013	.001	.014	.000	.010	.002	.007	.002						
.005	.007	.007	.000	.011	.006	.009	.006	.009	.006	.009	.006										
.003	.003	-.001	.001	-.006	.006	.001	.004	-.001	.002	-.001	.003	-.005	.004	-.001	.007	.003	.004	.003	.003		
.004	.000	.003	.002	.003	.002	.003	.001	.005	.002	.005	.002	.005	.002								
.008	.020	.009	.021	.008	.020	.009	.016	.008	.017	.009	.017										
MENT AND CLEAR CREEK AGGREGATE																					
.005	.004	-.002	.002	-.002	.002	.000	.002	-.004	.002	-.004	.002	-.006	.003	-.007	.004	-.005	.003	-.006	.002	-.006	.002
.011	.005	.011	.001	.005	.001	.007	.003	.007	.005	.006	.003	.010	.002	.009	.002	.007	.003				
.003	.004	-.009	.006	-.004	.004	-.007	.005	-.009	.005	-.008	.005	-.010	.005	-.012	.008						
.002	.007	.009	.006	.011	.006	.009	.006	.007	.000	.000	.000										
.006	.010	-.008	.004	-.006	.003	-.005	.008	-.007	.007	-.008	.005	-.009	.008	-.004	.005	-.005	.005	-.003	.005		
.007	.001	-.008	.001	-.008	.001	-.008	.001	-.007	.002	-.009	.003	-.008	.002								
.001	.018	-.001	.020	-.001	.019	-.001	.017	-.002	.016	-.004	.015										
NT AND CLEAR CREEK AGGREGATE																					
.001	.000	.003	.000	.003	.003	.005	.001	.001	.001	.002	.002	-.001	.000	-.003	.001	-.002	.002	-.002	.001	-.003	.000
.012	.008	.014	.005	.007	.003	.009	.006	.008	.005	.009	.006	.014	.002	.011	.005	.009	.003				
.013	.030	.014	.047	.020	.058	.022	.068	.021	.080	.028	.085	.026	.094	.030	.099						
.000	.000	.007	.013	.013	.000	.007	.013	.009	.006	-.002	.007										
.002	.001	-.005	.003	-.004	.005	-.003	.004	-.003	.007	-.007	.004	-.004	.006	.001	.003	-.001	.006	.001	.004		
.003	.005	-.002	.005	-.001	.006	-.001	.005	-.002	.007	-.001	.005	.000	.005								
.003	.016	.005	.019	.006	.024	.006	.025	.006	.024	.005	.035										
NT AND REPUBLICAN RIVER AGGREGATE																					
.272	.064	.322	.073	.368	.083	.410	.088	.458	.091	.495	.092	.533	.094	.574	.097	.601	.100	.634	.106	.659	.111
.387	.182	.450	.191	.504	.196	.502	-	.573	.032	.604	-	.646	-	.690	-	-	-	-	-	-	-
.493	.016	.558	.028	.623	.045	.686	.067	.742	.073	.777	.078	.840	.084								
.230	.020	.293	.014	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
.191	.076	.238	.092	.288	.103	.345	.110	.403	.132	.464	.136	.519	.146	.575	.160	.591	.334				
.386	.072	.447	.076	.504	.080	.560	.078	.609	.081	.653	.080	.689	.079								
.326	.302	.385	.320																		
T AND REPUBLICAN RIVER AGGREGATE																					
.019	.010	.024	-	.024	-	.021	.014	.028	.015	.031	.017	.035	.018	.046	.020	.046	.022	.057	.023	.060	.028
.035	.036	.040	.035	.050	.041	.039	.045	.023	.003	.025	.003	.029	.002	.027	.005	.024	.003				
.130	.077	.152	.084	.173	.091	.189	.095	.205	.097	.216	.103	.224	.106								
.011	.006	.020	.014	.025	.007	.020	.014	.013	.013	.018	.007										
.006	.002	-.006	.004	-.005	.008	-.006	.005	-.006	.005	-.006	.007	-.005	.008	.000	.009	.000	.007	.002	.001		
.001	.002	-.002	.002	-.001	.003	-.001	.004	.000	.002	-.001	.003	.000	.003								
.031	.136	.038	.158	.044	.178	.044	.195	.044	.211	.047	.222										
T AND REPUBLICAN RIVER AGGREGATE																					
.012	.005	.014	.005	.012	.004	.011	.004	.015	.006	.015	.006	.016	.006	.025	.006	.023	.008	.030	.006	.030	.007
.022	.005	.024	.003	.019	.002	.020	.004	.019	.002	.022	.002	.025	.003	.020	.006	.019	.003				
.046	.031	.049	.040	.051	.050	.058	.065	.067	-	.080	.125	.092	.169								
.007	.000	.013	.008	.025	.007	.018	.007	.015	.007	.011	.006										
.003	.004	.003	.004	.002	.003	.007	.001	.005	.004	.004	.003	.003	.005	.009	.006	.006	.007	.007	.006		
.000	.002	.001	.004	.002	.004	.002	.005	.002	.005	.004	.005	.004	.005								
.015	.046	.017	.048	.018	.049	.019	.053	.020	.065												

d in water at 73.4° F ± 3.0° F.

ges recorded in the column to the left.

contrast to expansion of 0.002 per cent and 0.005 per cent for the other specimens cast from the same batch.

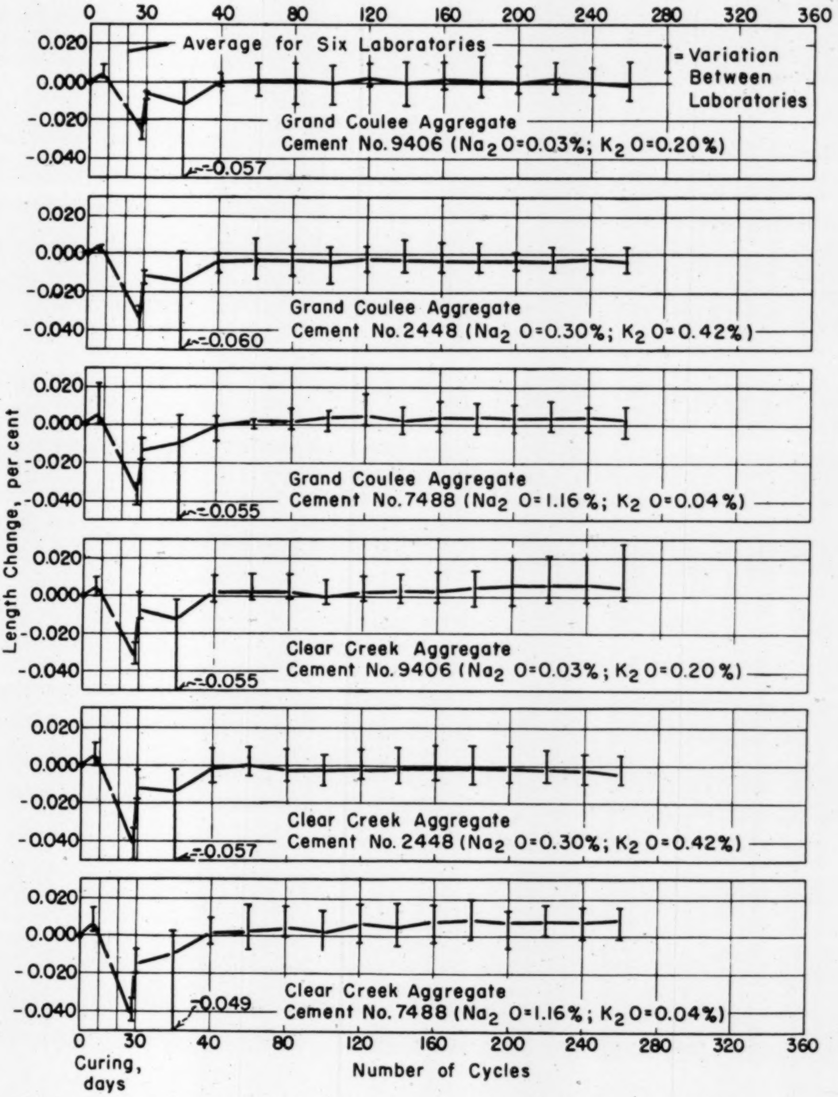

FIG. 4.—Results of the Proposed Tentative Method of Test for Potential Abnormal Expansion of Cement-Aggregate Combinations (Scholer Test) Using Grand Coulee (Columbia River) and Clear Creek Aggregates.

Expansion of the specimens containing Republican River aggregate and high-alkali cement proceeded uniformly after the initiation of heating-drying and cooling-wetting, attaining an average of 0.442 per cent after 200 cycles. Expansion of the specimens containing this aggregate and the very low-alkali cement attains an average of 0.018 per cent during 200 cycles, but laboratory No. 3 reported an average expansion of 0.051 per cent for this combination, the expansion of the three specimens of the combination ranging from 0.032 per cent to 0.082 per cent. Expansion of the combination composed of Republican River aggregate and the low-alkali cement of intermediate alkali content (No. 2448) is moderate, averaging 0.044 per cent after 200 cycles. The expansion reported by laboratory No. 3 again is highest, averaging 0.173 per cent and ranging from 0.118 per cent to 0.210 per cent among the three specimens.

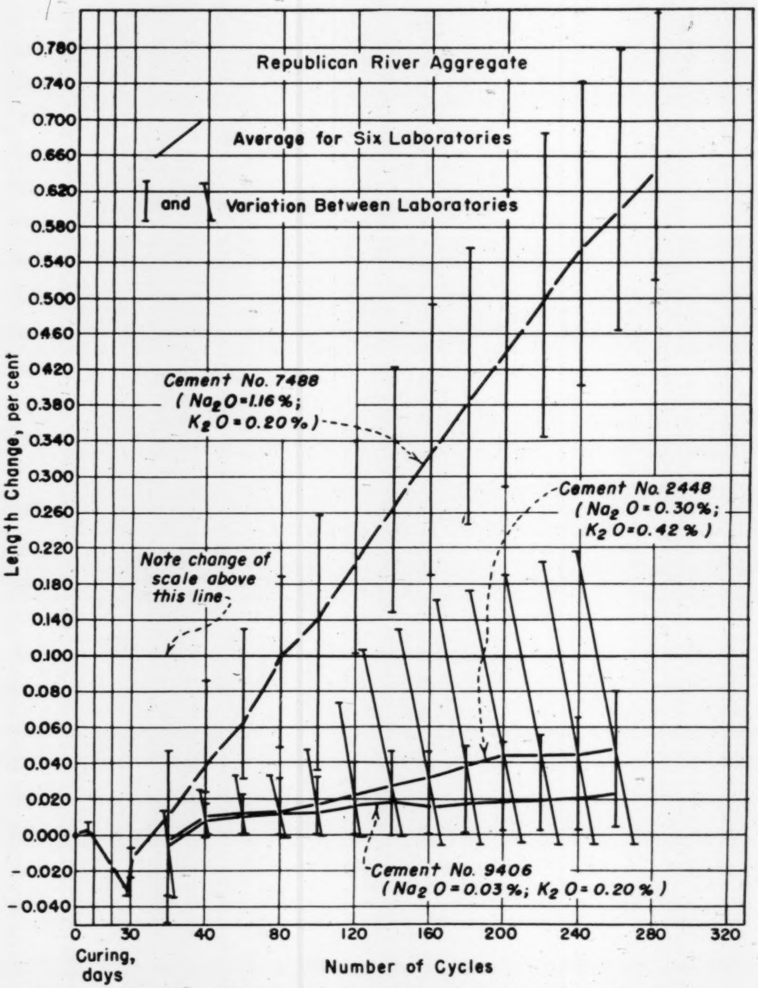

FIG. 5.—Results of the Scholer Test Using Republican River Aggregate.

Reproducibility of the test is not satisfactory (Table V and Figs. 4 and 5), apparently because of variations in the heating and cooling and wetting and drying cycles from one laboratory to another within the requirements of the procedure. Reproducibility is especially poor for combination of Clear Creek aggregate and the very low-alkali cement and all combinations containing Republican River aggregate, largely because of the inordinate expansion reported by laboratory No. 3.

Tentative Method of Test for Potential Alkali Reactivity of Cement-Aggregate Combinations (C 227)[7]*:*

As a supplement to the cooperative tests, one laboratory performed the Tentative Method of Test for Potential Alkali Reactivity of Cement-Aggregate Combinations (C 227), using combinations of the three aggregates and cements. At an age of 12 months, only mortars containing the high-alkali cement or the low-alkali cement of intermediate alkali content (No. 2448) and fine aggregate derived by crushing of the gravel from the Republican River had developed excessive expansion (Table VI). The Republican River sand was not included in this test. Mortars containing sand or crushed gravel from the Columbia River or Clear Creek expanded 0.000 to 0.030 per cent during 12 months of storage. For these materials the expansion up to 1 yr increased with alkali content of the cement; other workers (**6, 7**) using other aggregates have found the reverse to be true.

At an age of 9 months, spots of gel became evident on specimens containing Republican River crushed gravel and high-alkali cement or the low-alkali cement of intermediate alkali content (No. 2448). At an age of 12 months the specimens containing this aggregate and cement No. 2448 were cracked visibly and had expanded 0.154 per cent. With the high-alkali cement, this aggregate produced an expansion of 0.290 per cent in the same period.

TABLE V.—REPRODUCIBILITY OF THE PROPOSED TENTATIVE METHOD OF TEST FOR POTENTIAL ABNORMAL EXPANSION OF CEMENT-AGGREGATE COMBINATIONS.[a]

Cement		Aggregate	Average Expansion for Cooperating Laboratories, per cent	Range in Expansion Within the Laboratories, per cent			Range in Average Expansion Between the Laboratories, per cent		
	Alkali Content, per cent (Na_2O equivalent)			Maximum	Minimum	Average	Maximum	Minimum	Average
No. 7488	1.19	Sand and gravel, Grand Coulee Dam, Wash.	0.004	0.015	0.006	0.009	0.015	0.002	0.005
No. 2448	0.58		−0.003	0.007	0.002	0.004	0.009	0.000	0.004
No. 9406	0.17		0.001	0.013	0.000	0.004	0.014	0.000	0.006
No. 7488	1.19	Sand and gravel, Clear Creek, near Denver, Colo.	0.008	0.006	0.002	0.004	0.020	0.002	0.009
No. 2448	0.58		−0.001	0.006	0.001	0.003	0.019	0.002	0.009
No. 9406	0.17		0.006	0.058	0.000	0.012	0.024	0.003	0.011
No. 7488	1.19	Sand and gravel, Republican River, near St. Francis, Kans.	0.442	0.196	0.045	0.101	0.335	0.001	0.145
No. 2448	0.58		0.044	0.091	0.003	0.030	0.178	0.004	0.067
No. 9406	0.17		0.018	0.050	0.002	0.012	0.049	0.000	0.021

[a] Based upon results after 200 cycles of heating-drying and cooling-soaking.

SIGNIFICANCE OF THE CONROW TEST

Additional data are required to correlate the proposed Tentative Method of Test for Potential Volume Change of Cement-Aggregate Combinations (Conrow test) with performance of concrete in structures. However, preliminary investigations conducted largely by A. D. Conrow indicate that the method will reveal many cement-aggregate combinations showing distress in field exposure tests. Also, no conditions established in the test are beyond those expectable in natural exposure in many parts of the United States.

Based upon extensive tests in the laboratory and field exposure, Conrow concludes that cement-aggregate combinations to be subjected in service to wide variations of

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[7] Tentative Method of Test for Potential Alkali Reactivity of Cement-Aggregate Combinations (C 227 – 52 T), 1952 Book of ASTM Standards, Part 3, p. 44.

TABLE VI.—RESULTS OF TENTATIVE METHOD OF TEST FOR POTENTIAL ALKALI REACTIVITY OF CEMENT-AGGREGATE COMBINATIONS (ASTM METHOD C 227).[a]

Cement		Aggregate	Flow, per cent	Length Change, per cent							
	Alkali Content, per cent (Na_2O equivalent)			1 month	2 months	3 months	6 months	9 months	12 months	18 months	24 months
No. 7488	1.19	Crushed gravel, Grand Coulee Dam, Wash.	112.9	0.012	0.016	0.020	0.024	0.026	0.028		
No. 2448	0.58		99.5	0.002	0.002	0.004	0.007	0.008	0.008		
No. 9406	0.17		103.5	0.000	0.000	0.000	−0.001	0.000	0.000		
No. 7488	1.19	Sand, Grand Coulee Dam, Wash.	105.4	0.012	0.014	0.020	0.025	0.025	0.026		
No. 2448	0.58		105.0	0.001	0.000	0.004	0.006	0.006	0.008		
No. 9406	0.17		99.8	−0.004	−0.006	−0.003	0.000	0.000	0.000		
No. 7488	1.19	Crushed gravel, Clear Creek, near Denver, Colo.	102.6	0.015	0.016	0.020	0.023	0.023	0.024		
No. 2448	0.58		111.2	0.006	0.007	0.009	0.011	0.011	0.012		
No. 9406	0.17		100.4	0.001	0.001	0.004	0.006	0.006	0.006		
No. 7488	1.19	Sand, Clear Creek, near Denver, Colo.	111.6	0.018^b	0.018^b	0.022^b	0.028^b	0.028^b	0.030^b		
No. 2448	0.58		109.6	0.006	0.006	0.010	0.013	0.012	0.014^c		
No. 9406	0.17		101.6	−0.002	−0.002	0.001	0.005	0.004	0.005		
No. 7488	1.19	Crushed gravel, Republican River, St. Francis, Kans.	99.8	0.048	0.146	0.209	0.276	0.288^c	0.290		
No. 2448	0.58		118.2	0.006	0.008	0.015	0.072	0.122^c	0.154^d		
No. 9406	0.17		103.3	0.000	−0.002	0.003	0.004	0.005	0.005		

[a] Two specimens prepared for each combination, except as indicated.

[b] One specimen only.

[c] Gel spots evident.

[d] Specimens cracked.

temperature and degree of saturation are not acceptable if expansion in the proposed method of test exceeds 0.200 per cent when the specimens have attained an age of 1 yr. During development of the proposed test, Conrow prepared 3 by 3 by 11-in. concrete beams from 125 combinations of sand-gravel aggregate and cements now in use in midwestern United States. The cements included all portland cements marketed in that area as well as several portland-pozzolan blends.

TABLE VII.—RESULTS OF MICROSCOPICAL EXAMINATION OF SPECIMENS SUBJECTED TO THE PROPOSED TENTATIVE METHOD OF TEST FOR POTENTIAL VOLUME CHANGE OF CEMENT-AGGREGATE COMBINATIONS FOR APPROXIMATELY 2 YR.

Cement		Aggregate	Large Fractures	Microfractures	Aggregate Cement Bond	Unhydrated Clinker Particles	Calcium Hydroxide	Evidence of Alkali-Aggregate Reaction		Calcium Sulfoaluminate
	Alkali Content, per cent (As Na_2O)							Silica Gel	Reaction Rims	
No. 7488	1.19	Grand Coulee Dam, Wash.	D	B	S	B	C	E	E	A
No. 2448	0.58		D	C	S	B	B	E	E	A
No. 9406	0.17		D	B	S	C	C	E	E	C
No. 7488	1.19	Clear Creek, near Denver, Colo.	D	B	S	B	B	E	E	A
No. 2488	0.58		D	B	S	B	A	E	E	A
No. 9406	0.17		D	B to A	S	B	C	E	E	A
No. 7488	1.19	Republican River, near St. Francis, Kans.	B[a]	B to A	S to P	B[b]	B	A	A	A[c]
No. 2448	0.58		C[a]	B	S to P	B	A	C	C	A
No. 9406	0.17		D	B	S to P	B	C	D	E	C

NOTE.—

A = abundant. E = absent.

B = common. S = satisfactory.

C = sparse. P = poor.

D = rare.

[a] Fractures are commonly lined by secondary deposits.

[b] Cement paste shows "granular" aspect.

[c] Calcium carbonate and calcium sulfoaluminate occur in fractures as well as in voids.

Specimens from all of these combinations have been subjected to exposure in test plots and to the procedure of the Conrow test, except that the specimens subjected to the test procedure were stored in water in tanks rather than in sealed cans. Thirty-one of the cement-aggregate combinations have been exposed in the test plot for 6 yr. The data indicate that a deleterious degree of expansion is to be expected in field exposure if expansion exceeds 0.200 per cent in the laboratory test.

MICROSCOPICAL EXAMINATION OF THE TEST SPECIMENS

Specimens Subjected to the Conrow Test:

The specimens examined microscopically had been under test in accordance with the proposed method of test for approximately two years.[8] The results of examination by means of stereoscopic and petrographic microscopes are summarized in Table VII. Deterioration of mortar in the specimens ranges from slight to moderate. Deterioration is indicated by open fractures, minute fractures ramifying through the cement paste (microfractures), secondary deposits in voids and fractures, development of a "granular" appearance in the cement paste, and rupture of the bond between particles of aggregate and the cement paste. Carbonation of the cement paste is slight in all specimens in this series. Deterioration is most pronounced in specimens containing Republican River sand and the low-alkali cement of intermediate alkali content or the very low-alkali cement (Nos. 2448 and 9406, respectively). Only slight deterioration is evident in specimens containing Clear Creek sand or Columbia River (Grand Coulee Dam) fine aggregate.

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[8] The specimens containing Republican River aggregate were 660 days old whereas those containing Clear Creek sand or Columbia River (Grand Coulee Dam) fine aggregate were 772 days old.

The degree of deterioration corresponds well with the evidence of alkali-aggregate reaction in the mortar. However, there is no specific correlation in specimens containing Republican River sand between evident deterioration and measured expansion. The specimens containing Republican River sand and the very low-alkali cement (No. 9406) show less deterioration than do specimens containing this sand and the high-alkali cement (No. 7488), even though the very low-alkali cement mortar expanded more.

In specimens containing the Republican River sand, alkali-aggregate reaction involves particles of opaline chalks, rhyolites, andesites, and chalcedonic cherts. Reaction is most pronounced in particles of opaline chalk. In the high-alkali cement mortar, silica gel and calcium sulfoaluminate are copious in voids and fractures; reaction rims are abundant; and carbonation of the cement paste is slight. In the specimens containing the low-alkali cement of intermediate alkali content (No. 2448), attack upon the aggregate is less pronounced; reaction rims are sparse; silica gel and calcium sulfoaluminate are common in voids; and carbonation of the cement paste is slight.

In the very low-alkali cement specimens containing Republican River sand, no reaction rims were observed on potentially alkali reactive particles. Silica gel occurs only in a few voids, but calcium sulfoaluminate is common in voids.

The silica gel in the specimens includes two types: (1) white, cloudy gel, which is either homogeneous or contains microcrystalline calcium carbonate (calcite) and (2) colorless, clear gel. The index of refraction ranges from about 1.41 to 1.51 in several occurrences. Spectrographic and flame photometer analyses of a deposit of silica gel from the interior of a specimen containing Republican River sand and the low-alkali cement reveal the molar ratio $CaO:Na_2O$ to be 2.5. This ratio must be considered approximate only because of the very small size of the sample analyzed. No calcium carbonate was visible microscopically in the material analyzed. For a sample of silica gel from the exterior surface of a specimen containing Republican River sand and the high-alkali cement, the $CaO:Na_2O$ ratio was found to be 5.3, but considerable calcium carbonate (calcite) was identified microscopically.

Particles of potassium feldspars in the Republican River sand commonly are associated with a radial pattern of microfractures, regardless of the cement used. Similar microfractures are related spatially to particles of plagioclase feldspars occurring in the finest fractions of the Columbia River (Grand Coulee Dam) fine aggregate. They occur also to a minor extent in relation to particles of feldspar in the Clear Creek sand.

Microfractures are sparse to moderately abundant in specimens containing Clear Creek sand or Columbia River (Grand Coulee Dam) fine aggregate. Calcium sulfoaluminate is sparse to abundant in voids in these specimens. No silica gel is observed.

Specimens Subjected to the Scholer Test:

The specimens examined had been under test in accordance with the proposed method for approximately 500 cycles of heating-drying and cooling-soaking.[9] The results of the microscopical examination are summarized in Table VIII.

Deterioration of the concrete in the specimens ranges from slight to extreme. Distress is indicated by the same features as were described in the previous section. Deterioration is related closely to the measured expansion and to evidence of alkali-aggregate reaction. Distress is greatest in the specimens containing Republican River aggregate and the high-alkali cement. In these specimens alkali-aggregate reaction is indicated by reaction rims on particles of opaline chalks, rhyolites, andesites, and chalcedonic cherts. Silica gel and calcium sulfoaluminate are abundant in voids and fractures.

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[9] The specimens containing Republican River aggregate had been subjected to 480 cycles whereas those containing Clear Creek or Columbia River (Grand Coulee Dam) aggregate had been subjected to 540 cycles.

Distress is moderate in the specimens containing Republican River aggregate and the low-alkali cement of intermediate alkali content (No. 2448). Reaction rims are sparse, and silica gel and calcium sulfoaluminate occur sparsely or commonly in voids. In specimens containing this aggregate and the very low-alkali cement, no reaction rims were detected; silica gel occurs only in a very few voids, but calcium sulfoaluminate occurs commonly in voids.

Microfractures are sparse to moderately abundant in the specimens containing Clear Creek or Columbia River (Grand Coulee Dam) aggregate. A very small amount of silica gel was discovered in specimens containing high-alkali cement and Clear Creek aggregate. No other evidence of alkali-aggregate reaction was detected. However, small amounts of calcium sulfoaluminate occur in voids.

TABLE VIII.—RESULTS OF MICROSCOPICAL EXAMINATION OF SPECIMENS SUBJECTED TO THE PROPOSED TENTATIVE METHOD OF TEST FOR POTENTIAL ABNORMAL EXPANSION OF CEMENT-AGGREGATE COMBINATIONS FOR APPROXIMATELY 500 CYCLES.

Cement		Aggregate	Large Fractures	Micro-fractures	Aggregate Cement Bond	Carbonation of the Cement Paste	Evidence of Alkali-Aggregate Reaction		Calcium Sulfoaluminate
	Alkali Content, per cent (As Na_2O)						Silica Gel	Reaction Rims	
No. 7488	1.19	Grand Coulee Dam, Wash.	C[a]	B	S[b]	C	E	E	B[c]
No. 2448	0.58		D	B	S[b]	C	E	E	C
No. 9406	0.17		D	C	S[b]	D	E	E	C
No. 7488	1.19	Clear Creek, near Denver, Colo.	C[a]	A	S[a]	D to C	D	E	C
No. 2448	0.58		C	B	S[b]	D to C	E	E	C
No. 9406	0.17		C	B	S[b]	D to C	E	E	C
No. 7488	1.19	Republican River, near St. Francis, Kans.	A[a]	A	S to P	B	A[c]	A	A[c]
No. 2448	0.58		C[a]	A	S	B	C	C	B
No. 9406	0.17		D[a]	A	S	B	D	E	B

NOTE.—

A = abundant.
B = common.
C = sparse.
D = rare.
E = absent.
S = satisfactory.
P = poor.

[a] Fractures commonly or usually lined by secondary deposits.

[b] Except for sparse soft particles.

[c] Deposits occur in fractures as well as in voids.

MECHANISM CAUSING EXPANSION OF SPECIMENS IN THE CONROW TEST

The cooperative tests on the Conrow method, together with tests of most of the same cement-aggregate combinations in accordance with ASTM Method C 227, demonstrate that the mechanism causing expansion differs fundamentally in the two procedures, although interaction of cement alkalies and the aggregate will occur during the Conrow test if alkali-reactive constituents are present in the aggregate.

Neither method produced inordinate expansion in combinations containing Columbia River (Grand Coulee Dam) or Clear Creek aggregate. With Republican River sand, the Conrow test produced high expansion with all three cements used, maximum expansion being obtained with the cement containing only 0.17 per cent total alkalies (as equivalents of Na_2O). In the Conrow test applied by one cooperating laboratory to a mixture of crushed Republican River gravel and natural Republican River sand, expansion was much reduced regardless of the cement used, in comparison with expansion of specimens containing the natural sand as the entire aggregate. Moderate expansion was attained in this group of specimens only with the high-alkali cement (1.17 per cent total alkalies as Na_2O). In Method C 227, expansion at 12 months is very low with the very low-alkali cement, moderate with the low-alkali cement of intermediate alkali content, and high with the high-alkali cement.[10]

Expansion of specimens containing crushed Republican River gravel in the Conrow test probably is produced largely by alkali-aggregate reaction. The expansion observed at 380 days on specimens containing this aggregate and high-alkali cement (0.144 per cent) is less than the expansion attained in Method C 227 at 1 yr by specimens containing similar aggregate and the same cement (0.290 per cent), the difference probably being due largely to the lower storage temperatures specified in the Conrow test.

These relationships indicate that the deleterious activity of the Republican River aggregate in the Conrow test depends at least in part upon properties which are altered markedly by crushing. It is likely that these properties are physical rather than compositional, inasmuch as crushing and sieving probably do not alter the mineralogic composition of the aggregate significantly. Crushing obviously changes the surface texture or bonding characteristics of the aggregate; and to a degree rigidity or compressibility will be changed by introduction of random fractures in the brittle and more cleavable particles. Such changes probably will be most pronounced in feldspars and coarse grained granites which are ubiquitous constituents of the deleterious sand-gravel aggregates of Kansas and Nebraska.

These observations are consistent with the tentative conclusion that pebbles and natural sand grains composed of relatively unweathered, single crystals of potassium feldspars or coarse grained granites should be viewed with suspicion, especially in concretes subjected to wide variations of temperature and degree of saturation. In the cooperative tests, the feldspars and coarse grained granites are abundant only in the Republican River aggregate, which contains also a significant proportion of rock types known to be deleteriously reactive with cement alkalies. Consequently, the deleterious actions involving processes other than alkali-aggregate reaction can be distinguished only indirectly. However, in tests of concrete involving a procedure very similar to the proposed method of test, Higginson and Kretsinger (**8**) observed great expansion of certain combinations in which the aggregate was composed wholly of selected coarse-grained potassium feldspar, quartz, or combinations of potassium feldspar and quartz. Additional studies should be made to establish definitely the performance of feldspars in concrete or mortars subjected to various conditions of curing and storage.

The data warrant no statement at this time concerning the specific physical and physical-chemical processes by which the expansion develops during the proposed test. Conrow (**2**) has concluded that calcium hydroxide released by hydration of the cement plays a part in the adverse reaction. It is probable that the process involves also other phenomena associated with the hydration of portland cement.

CONCLUSIONS

Approval of Method of Test:

On the basis of the test results, Subcommittee II-b approves the acceptance as tentative of the Method of Test for Potential Volume Change of Cement-Aggregate Combinations (Conrow test). The proposed Method of Test for Potential Abnormal Expansion of Cement-Aggregate Combinations (Scholer test) is not approved at this time, primarily because reproducibility of results is inferior.

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[10] Other workers (**7**), using other aggregates, have found low-alkali cements to produce the maximum expansion at later ages.

Significance of the Conrow Test:

Additional data are required to establish a specific correlation between the results of the Method of Test for Potential Volume Change of Cement-Aggregate Combinations and performance of the cement-aggregate combinations in field service. Data now available indicate that cement-aggregate combinations whose expansion in the proposed method of test equals or exceeds 0.200 per cent at an age of 1 yr should be considered unsatisfactory for use in concrete or mortar exposed to wide variations of temperature and degree of saturation with water.

Reproducibility of the Conrow Test:

Reproducibility is considered satisfactory if in the proposed method of test the percentage expansion of any specimen does not differ by more than 0.003 from the average value of the expansion of all test specimens molded from the same batch of mortar; if the average value so determined exceeds 0.020 per cent, reproducibility of the test is considered satisfactory if the expansion of all test specimens molded from the same batch of mortar does not differ from that average value by more than 15 per cent of that average value.

Mechanism of Cement-Aggregate Reaction in the Conrow Test:

The data indicate that the cement-aggregate reactions producing adverse expansion during the proposed test largely are independent of alkali-aggregate reaction, although interaction of cement alkalies and the aggregate will occur during the test if alkali-reactive constituents are present in the aggregate.

REFERENCES

(1) C. H. Scholer, "A Wetting and Drying Test for Predicting Cement-Aggregate Reaction," *Proceedings*, Am. Soc. Testing Mats., Vol. 49, p. 942 (1949).

(2) A. D. Conrow, "Studies of Abnormal Expansion of Portland-Cement Concrete," *Proceedings*, Am. Soc. Testing Mats., Vol. 52, p. 1205 (1952).

(3) R. C. Mielenz, "Potential Reactivity of Aggregate in Concrete and Mortar," ASTM BULLETIN, No. 193, October, 1953, p. 41 (TP173).

(4) W. E. Gibson, "A Study of Map-Cracking of Sand-Gravel Concrete Pavements," *Proceedings*, Highway Research Board, Vol. 18, Part I, p. 227 (1938).

(5) V. E. Wolkodoff and V. S. Krishnaswamy, "Petrographic Examination of Concrete Aggregates Used in Cooperative Tests Sponsored by Subcommittee II-b, ASTM Committee C-9," *Petrographic Memorandum No. 53-108*, U. S. Department of the Interior, Bureau of Reclamation, 6 pp. (1953).

(6) D. O. Woolf, "Reaction of Aggregate with Low-Alkali Cement," *Public Roads*, Vol. 27, p. 50 (1952).

(7) W. C. Hanna, "Unfavorable Chemical Reactions of Aggregates in Concrete and a Suggested Corrective," *Proceedings*, Am. Soc. Testing Mats., Vol. 47, p. 986 (1947).

(8) E. C. Higginson and D. G. Kretsinger, "Prediction of Concrete Durability from Thermal Tests of Aggregate," *Proceedings*, Am. Soc. Testing Mats., Vol. 53, p. 991 (1953).

REPORT OF COMMITTEE C-11

ON

GYPSUM*

Committee C-11 on Gypsum held two meetings during the past year: in Atlantic City, N. J., on July 1, 1953, and in Washington, D. C., on February 3, 1954.

The committee now consists of 20 members, of whom 9 are classified as producers, 3 as consumers, and 8 as general interest members.

The new officers elected at the Washington meeting for the ensuing term of two years are as follows:

Chairman, G. W. Josephson.
Vice-Chairman, B. W. Nies.
Secretary, O. H. Storey, Jr.

Committee C-11 is recommending to the Board of Directors that its scope be revised as set forth below by the addition of the underlined words:

> "The formulation of specifications, methods of test, and definitions relating to gypsum, calcined gypsum, gypsum products, *and aggregates for use therewith.*"

RECOMMENDATIONS ACCEPTED BY THE ADMINISTRATIVE COMMITTEE ON STANDARDS

Subsequent to the 1953 Annual Meeting, Committee C-11 presented to the Society through the Administrative Committee on Standards the following recommendations:

Tentative Specifications for:

Gypsum Formboard (C 318 – 53 T).

Revision of Tentative Specification for:

Inorganic Aggregates for Use in Interior Plaster (C 35 – 52 T), jointly with Committee C-7 on Lime.[1]

These recommendations were accepted by the Standards Committee on September 9, 1953, and the new and revised tentative specifications appear in the 1953 Supplement to Book of ASTM Standards, Part 3.

NEW TENTATIVE

The Administrative Committee on Standards accepted new Tentative Specifications for Gypsum Concrete on September 9, 1953, which was assigned the designation of C 317 – 53 T. Subsequent to this action, Committee C-11 in reviewing the specifications recommended deletion of any reference to the use of mineral aggregate designated as Type II. Committee C-11 therefore now recommends acceptance of the Tentative Specifications for Gypsum Concrete as appended hereto.[2]

REVISION OF STANDARDS, IMMEDIATE ADOPTION

The committee recommends for immediate adoption the following revisions of standards, and accordingly asks for the necessary nine-tenths affirmative vote at the Annual Meeting in order that these recommendations may be referred to letter ballot of the Society:

Standard Specifications for Gypsum Wallboard (**C 36 – 52**).[3]

Section 2.—In line 5, delete "or other fibrous material."

Add the following sentence to the end of the section: "The back surface of insulating gypsum wallboard shall in addition be covered with aluminum foil."

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13–18, 1954.

[1] See Editorial Note, p. 378.

[2] The new tentative was accepted by the Society and appears in the 1954 Supplement to Book of ASTM Standards, Part 3.

[3] 1952 Book of ASTM Standards, Part 3.

Section 4.—In line 3, change "one" to "three."

Delete the last sentence of this section.

Section 5.—In Paragraph (*a*), change the last sentence to read as follows:

> The average thickness of the edge of recessed or tapered edge board shall be at least 0.010 in. less than the average thickness of the board as determined in accordance with Sections 39 to 41 of ASTM Methods C 26.[4]

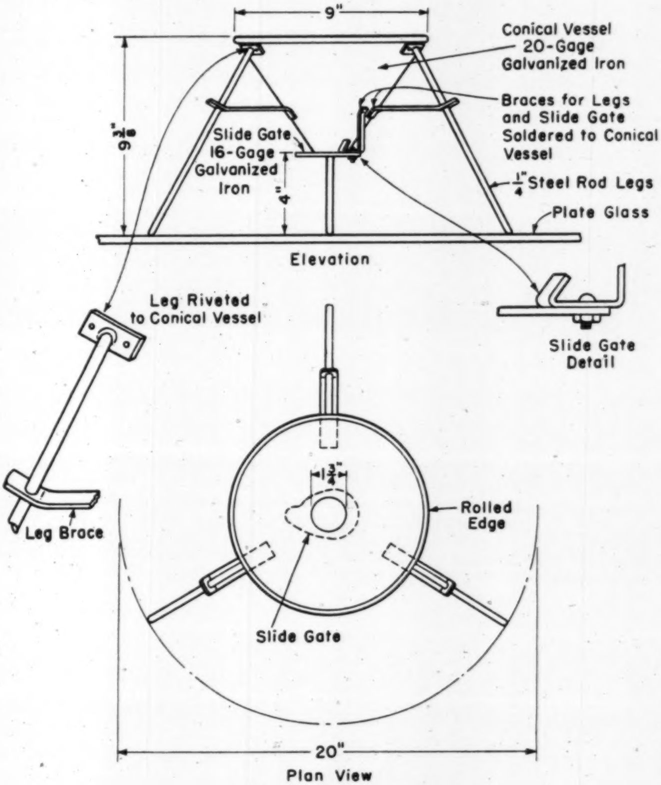
9"
Conical Vessel
20-Gage
Galvanized Iron
Braces for Legs
and Slide Gate
Soldered to Conical
Vessel
1/4" Steel Rod Legs
Plate Glass
6 3/8"
Slide Gate
16-Gage
Galvanized
Iron
4"
Elevation
Leg Riveted
to Conical Vessel
Slide Gate
Detail
Leg Brace
1 3/4"
Rolled
Edge
Slide Gate
20"
Plan View

FIG. 1.—Consistometer.

In Paragraph (*b*), add an additional width of "16 in."

In Paragraph (*c*), add a $\frac{5}{8}$-in. board as being available in 4-ft. to 14-ft. lengths.

Section 6.—Change Note 2 to read as follows:

NOTE 2.—Gypsum wallboard is available with the face surface predecorated.

New Section.—Add the following new Section 7 and renumber the subsequent sections accordingly:

> 7. *Insulating Gypsum Wallboard.*—(*a*) Insulating gypsum wallboard shall meet all the requirements specified above, except that in addition the back surface shall be covered with pure bright-finished aluminum foil.
>
> (*b*) When tested in accordance with Procedure A of the Tentative Methods of Test for Measuring Water Vapor Transmission of Materials in Sheet Form (ASTM Designation: E 96), the permeance of insulating gypsum wall board shall not exceed 0.30 perm for the condition of 50 per cent relative humidity on Side I, the face of the board, and 0 per cent relative humidity on Side II, the foil-covered back of the board.

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[4] See proposed revision of Method C 26 in this report.

Standard Methods of Testing Gypsum and Gypsum Products (**C 26 – 52**).[3]

Section 3.—Add the following new note prior to the present note to this section:

NOTE.—For suggested method of sieving gypsum through a No. 325 (44-micron) sieve, see the Appendix.

Sections 19 to 21.—Change the center heading preceding these sections to read: "Normal Consistency of Gypsum Concrete and Gypsum Plaster."

Section 19.—Add the following new Paragraph (*d*):

(*d*) *Consistometer.*—The consistometer (Fig. 3) shall consist of a conical vessel *A*, made of noncorroding, nonabsorbent material and shall have an inside diameter of 9 in. at the top and 1¾ in. at the bottom, and a height of 5½ in. It shall be provided with a sliding gate *B*, at the bottom and supported so that the bottom is 4 in. above the base plate *C*. The base plate shall be of plate glass, free of scratches and about 18 in. square.

New Figure.—Add a new Fig. 3 (the accompanying Fig. 1).

Section 20.—Change the heading for this section to read "Procedure for Gypsum Plaster."

New Section.—Add a new Section 21 to read as follows, renumbering the subsequent sections accordingly:

21. *Procedure for Gypsum Concrete.*

(*a*) The consistometer and the base plate shall be clean and dry and the sliding gate shall be closed.

(*b*) A 2000-g. sample shall be sifted into a known volume of water. After allowing the sample to soak for 1 min., the mixture shall be stirred for 3 min. to an even fluidity. The mixture shall then be poured into the consistometer until level with the top. The sliding gate shall then be rapidly and completely opened, allowing the mixture to run out freely upon the base plate. When the sliding gate is opened care should be exercised to avoid jarring the consistometer.

(*c*) The resulting patty on the base plate shall then be measured along its major and minor axes and the average diameter determined.

NOTE.—The addition of 0.50 g. of commercial retarder to the mixing water is required when determining normal consistency. No retarder shall be added when preparing specimens for compressive strength tests.

Section 21.—In Paragraph (*b*), change the heading to read "Gypsum Mixtures Containing Aggregates, Except Gypsum Concrete."

Add a new Paragraph (*c*) to read as follows:

(*c*) *Normal Consistency, Gypsum Concrete.*—Gypsum concrete shall be considered of normal consistency when a patty diameter of 15 ± ½ in. is obtained when tested in accordance with Section 21. Normal consistency shall be expressed as the number of milliliters of water required to be added to 100 g of the gypsum concrete.

New Section.—Add a new Section 23 on Density to read as follows and renumber the subsequent sections accordingly:

23. The density of gypsum concrete, expressed in pounds per cubic foot, shall be determined by multiplying by 0.095 the total weight in grams of the five compressive strength cube specimens, after drying (Section 21).

Section 26.—In Paragraph (*b*), change the third and fourth sentences to read as follows: "Place the cubes in the molds in moist air (90 per cent to 100 per cent humidity). The cubes may be removed from the molds as soon as thoroughly hardened, but must be retained in the moist air not less than 24 hr. total. Store at a temperature not less than 70 F. (21.16 C) nor more than 100 F. (37.86 C) in an atmosphere having a relative humidity of not more than 50 per cent."

Section 31(c).—Change the last sentence of this section to read as follows: "The weight of the residue is the weight of insoluble matter."

Section 34.—In line 1, change "ten" to "five."

Section 37.—Add the following after the first sentence: "When testing perforated gypsum lath, the specimens shall be so positioned that the load is not applied over any perforations."

New Sections.—Add the following new Sections 39 to 41, renumbering the subsequent sections accordingly:

39. *Test Specimens.*—The samples shall consist of a minimum of three boards. The individual boards to be tested shall be marked, scored both sides, and broken 1 ft. from each end and the two ends (1-ft. length) shall be discarded prior to tests. The remaining part of the board shall be retained and hereinafter referred to as a test specimen.

40. *Procedure.*—A self-reading micrometer gage shall be used for determining thickness measurement to 0.001 in. The micrometer shall be a 1-in., self-reading, hand micrometer with ¼-in. diameter anvils, graduated to 0.001 in. (equal to that manufactured by the Slocum Co.). The micrometer contact shall be firm but shall not indent the paper. Two micrometer readings shall be taken on each end of the board (total of four tests) 6 in. from each edge. The four micrometer readings shall be averaged and taken as the average thickness of the one test specimen. Two readings shall be taken on each edge of the test specimen, 6 in. from the end, and ⅜ in. from edge (total of four readings). These four tests shall be averaged and taken as the average thickness of the taper or recessed edge.

41. *Report.*—If the average thickness of the edge is found to be at least 0.010 in. less than the average thickness of the board, then the board shall be considered to have a recessed or tapered edge.

Appendix.—Add the following Appendix to the method:

APPENDIX

ALCOHOL WASH METHOD OF SIEVING GYPSUM AND GYPSUM PRODUCTS

It is impracticable to sieve dry gypsum through a No. 325 (44-micron) sieve, and water cannot be used as a washing agent without introducing errors due to hydration or solution.

Use isopropyl alcohol (99 per cent) as the washing agent. Place the alcohol in a vessel 1 to 2 in. larger in diameter than the sieve, to a depth above 2 in. Place an accurately weighed 50-g sample on a No. 325 (44-micron) sieve or, if desired, a coarser sieve up to and including the No. 100 (149-micron) sieve. Lower the sieve into the alcohol until the sample is wetted throughout. Lift the sieve out of the alcohol, with a swirling motion, permitting the alcohol to drain through the sample back into the vessel. Repeat this operation at least eight times and until the alcohol passes freely through the sieve and the sample is essentially free from fines. Wash the residue retained on the sieve with about 100 ml of clear alcohol, and then blot the bottom of the sieve with a soft, dry, lint-free cloth. Dry the sieve with the residue at 100 to 125 F. Shake the sieve on a mechanical shaker (Ro-Tap or equivalent) for exactly 2 min. Multiply by two the weight of material retained after shaking in order to obtain percentage of the original sample. If desired, to permit simultaneous determinations of coarser fractions, the residue after drying and before shaking may be transferred to a series of coarser sieves up to and including the No. 100, nested in sequential order above the No. 325 sieve. The alcohol may be reused after decanting or filtering, provided its strength does not fall below 95 per cent.

Standard Specifications for Gypsum Partition Tile or Block (**C 52 - 41**).[3]

Section 3(b).—Delete this section.

Section 4.—In line 1, change "1" to "$\frac{1}{2}$."

In line 3, change "ten" to "five."

Standard Specifications for Gypsum Sheathing Board (**C 79 - 52**).[3]

Section 5.—In line 3, change "one" to "three."

Delete the last sentence of this section.

Standard Specifications for Gypsum Lath (**C 37 - 50**).[3]

Section 1.—Change to read as follows by the addition of the italicized words and the deletion of those in brackets:

1. These specifications cover plain, perforated and *insulating* [and other mechanical key] types of gypsum lath, [which are] designed to be used as a base for the reception of gypsum plaster.

Section 2.—Change to read as follows by the addition of the italicized words and the deletion of those in brackets:

2. Gypsum lath shall consist of an incombustible core, essentially gypsum, with or without fiber but not exceeding 15 per cent of fiber by weight, and surfaced with paper [or other fibrous material] firmly bonded to the core. *The back surface of insulating gypsum lath shall be covered with aluminum foil.*

Sections 3 to 6.—Add a center heading preceding these sections entitled "Plain Gypsum Lath."

Section 3.—Change the introduction to this section to read as follows by the addition of the italicized words and the deletion of those in brackets:

3. When tested, either face up or face down, in accordance with the Standard Methods of Testing Gypsum and Gypsum Products (ASTM Designation: C 26) [of the American Society for Testing Materials], *the breaking loads of* specimens taken from the gypsum lath shall [carry] *be* not less than the following [loads without showing a breaking of the bond between the surfacing and the core]:

Section 4.—Change to read as follows by the addition of the italicized words and the deletion of those in brackets:

4. At least 0.25 per cent of the number of gypsum lath in a shipment, but not less than [ten] *three* lath, shall be so selected as to be representative of the shipment, and shall constitute a sample for purpose of tests. [When a shipment consists of more than one car or carrier load, a sample shall be taken from each car or carrier.]

Section 5(e).—Delete this section.

Section 6.—In Paragraph (*b*), first line, delete the word "their."

Delete the Note to this section.

New Sections.—Add a new Section 7 and a new Section 8 as follows, renumbering the subsequent sections accordingly:

7. *Perforated Gypsum Lath.*—Perforated gypsum lath shall meet the requirements for plain gypsum lath except that it shall have perforations not less than ¾ in. in diameter with one perforation for not more than 16 sq in. of lath, and except that the breaking loads when tested with the bearing edges parallel to the fiber of surfacing shall be not less than 20 lb for ⅜ in. thickness and not less than 30 lb for ½ in. thickness.

8. *Insulating Gypsum Lath.*—(*a*) Insulating gypsum lath shall meet the requirements for plain gypsum lath except that in addition the back surface shall be covered with a continuous sheet of pure bright finished aluminum foil.

(*b*) When tested in accordance with Procedure A of the Tentative Methods of Test for Measuring Water Vapor Transmission of Materials in Sheet Form (ASTM Designation: E 96) the permeance of insulating gypsum lath shall not exceed 0.30 perm for the condition of 50 per cent relative humidity on Side I, the face of the lath, and 0 per cent relative humidity on Side II, the foil-covered back of the lath.

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[5]

This report has been submitted to letter ballot of the committee, which consists of 20 members; 20 members returned their ballots, of whom 19 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

G. W. JOSEPHSON,
Chairman.

O. H. STOREY, JR.
Secretary.

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[5] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee C-11, jointly with Committee C-7, presented to the Society through the Administrative Committee on Standards the recommendation that the Tentative Specification for Inorganic Aggregates for Use in Interior Plaster (C 35 – 53 T) be revised. This recommendation was accepted by the Standards Committee on December 22, 1954, and the revised specification appears in the 1954 Supplement to Book of ASTM Standards, Part 3, and in the December, 1954, Compilation of ASTM Standards on Mineral Aggregates, Concrete, and Nonbituminous Highway Materials.

REPORT OF COMMITTEE C-12

ON

MORTARS FOR UNIT MASONRY*

Committee C-12 on Mortars for Unit Masonry held two meetings during the past year: on July 2, 1953, in Atlantic City, N. J., and on February 4, 1954, in Washington, D. C.

At the present time, the committee consists of 39 members, of whom 16 are classified as producers, 12 as consumers, and 11 as general interest members. There are 3 consulting members.

The election of officers for the ensuing two-year term resulted in the selection of the following:

Chairman, R. E. Copeland.

First Vice-Chairman, Harry C. Plummer.

Second Vice-Chairman, P. M. Woodworth.

Secretary, J. A. Murray.

REVISION OF TENTATIVE

The committee recommends that the Tentative Specifications for Mortar for Unit Masonry (**C 270 – 52 T**)[1] be revised as follows and continued as tentative.

Section 1.—Change the final paragraph to read as follows:

> Unless data are presented to show that the mortar meets the requirements of the property specifications, the proportion specifications shall govern.

Section 2(d).—Change to read as follows:

> (*d*) Admixtures or mortar colors shall not be added to the mortar at the time of mixing unless provided for in the contract specifications, and after the materials are so added, the mortar shall conform to the requirements of the property specifications.

Table I and Table II.—Change the designations for mortar types to read as follows and add the indicated footnote:

Mortar Type[a]	
M	(A-1)
S	(A-2)
N	(B)
O	(C)
K	(D)

[a] Mortar type designations in parentheses are the former type designations in effect prior to 1954. They are being temporarily retained to avoid confusion during the transition to the use of the newer designations, approved in June 1954.

Table II.—In the column headed "Parts by Volume of Masonry Cement," and in the line for the present "Type C Mortar," change the material within the parentheses to read "(type I or II)."

TENTATIVE CONTINUED WITHOUT REVISION

A study of the Tentative Specifications for Mortar for Reinforced Brick Masonry (**C 161 – 44 T**) is now under way. It appears that extensive modifications of this tentative may be necessary, but sufficient progress has not been made as yet to warrant submission of any proposed changes to letter ballot. The committee therefore recommends that

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13–18, 1954.

[1] 1952 Book of ASTM Standards, Part 3.

Specifications C 161 – 44 T be retained as tentative without revision.

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[2]

SUBCOMMITTEE ACTIVITIES

Subcommittee II on Research (F. O. Anderegg, chairman) has active study under way on pointing mortars and tests for the subjective properties involved in workability and plasticity. The subcommittee is also considering reinforced brick masonry and provision of properties to secure more wall strength by giving adequate attention to the factor of area of contact. Shrinkage cracking is being studied, especially from the effect of fines in the sand and flexibility of the mortar to adjust itself to movements.

Subcommittee IV on Specifications for Aggregates for Mortar (Stanton Walker, chairman) is considering the provision of an "escape clause" in the Tentative Specification for Aggregate for Masonry Mortar (C 144 T), based upon methods of tests for water retention and compressive strength now included in Specification C 270 T.

Subcommittee on Efflorescence (P. L. Rogers, chairman) is giving final review to comments on a report of cooperative tests prepared for publication in the ASTM BULLETIN.[3] A new draft of test methods is being prepared for presentation.

This report has been submitted to letter ballot of the committee, which consists of 39 members; 30 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

J. M. HARDESTY,
Chairman.

J. A. MURRAY,
Secretary.

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[2] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

[3] P. L. Rogers, "Developing a Test Method for Efflorescence of Masonry Mortar," ASTM BULLETIN, No. 200, September, 1954, p. 64 (TP190).

REPORT OF COMMITTEE C-13

ON

CONCRETE PIPE*

Committee C-13 on Concrete Pipe held one meeting during the year: in Chicago, Ill., on September 15 and 16, 1953. The Subcommittee on Low-Head Pressure Pipe Specifications met in Chicago on September 13 and 14, 1953.

The present membership of the committee consists of 36 members, of whom 17 are classified as producers, 16 as consumers, and 3 as general interest members.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, R. R. Litehiser.

Vice-Chairman, E. F. Bespalow.

Secretary, Howard F. Peckworth.

The committee has prepared a revision of its scope, which is indicated below by the addition of the italicized words. This revision is being presented to the Board of Directors for action.

> *Scope.*—The formulation of specifications, methods of test for concrete pipe (reinforced and unreinforced) used for constructing sewers, culverts, and for irrigation *and drainage.*

TENTATIVE REVISIONS OF STANDARDS

The committee recommends for publication tentative revisions of the following standards as indicated:

Standard Specifications for Concrete Sewer Pipe (**C 14 – 52**):[1]

Section 20.—Change Paragraph (*b*) to read as follows:

> (*b*) *Acceptance or Rejection as to Other than Strength Properties.*—In other than strength tests when not more than 20 per cent of the specimens fail to pass the requirements of the specification, the manufacturer may cull his stock and may eliminate whatever quantity of pipe he desires and must so mark those pipe that they will not be shipped. The required tests shall be made on the balance of the order and they shall be accepted if they conform to the test requirements.

Section 24.—Change to read as follows:

> 24. The planes of the ends of the pipe shall be perpendicular to their longitudinal axes subject to limits of variation as shown in Table III.

Table I.—Delete the Note which appears at the top of Table I.

Table III.—Amend Table III by the addition of the following requirements for "Length of Two Opposite Sides, in.," under the heading "Limits of Permissible Variation in":

(Nominal Size, Internal Diameter, in.)	Variation, in.
4	1/4
6	1/4
8	5/16
10	3/8
12	7/16
15	3/8
18	1/2
21	3/8
24	9/16

Delete the Note which appears at the top of Table III.

Figure 1.—Revise Fig. 1 to show an I-beam in both the cross-sectional view and the end view on top of the wooden bearing block. The upper bearing block and the I-beam shall extend the full length of the pipe over the bell exclusive of the socket. The I-beam shall be

labeled "Rigid steel member, I-beam or other type."

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13–18, 1954.

[1] 1952 Book of ASTM Standards, Part 3.

Standard Specifications for Reinforced Concrete Sewer Pipe (**C 75 - 52**):[1]

Section 20.—Change to read as follows:

20. A purchaser of pipe, whose needs require shipments at intervals over extended periods of time, shall be entitled to preliminary tests of not more than three sections of pipe covering each size in which he is interested. Pipe having a diameter greater than 72 in. shall be accepted on the basis of tests of absorption and compressive strength of concrete cores drilled from the barrel of the pipe, and by examination of the quality, amount, and accuracy of placement of the reinforcement. When mutually agreed upon by the purchaser and the seller, pipe having an internal diameter of 72 in. and less may also be accepted on the basis of tests of strength and absorption of drilled cores, in which case the specified strength requirements for full size pipe shall be waived. Cores drilled from the barrel of the pipe shall have a diameter not less than 3½ in. They shall be secured, prepared for testing, and tested by the methods prescribed in Standard Methods of Securing, Preparing and Testing Specimens from Hardened Concrete for Compressive and Flexural Strength (ASTM Designation: C 42).

When the cores cut from a section of pipe successfully meet the strength test requirement, the core-holes shall be plugged and sealed by the manufacturer in such a manner that the pipe section will meet all of the test requirements of this specification. Pipe sections, so sealed, shall be considered as satisfactory for use.

After these preliminary tests, a purchaser shall be entitled to additional tests in such numbers and at such times as he may deem necessary, provided that the total number of pipe tested shall not exceed 1 per cent of the pipe delivered.

Section 25.—Change to read as follows:

25 (*a*). *Acceptance or Rejection as to Strength Properties.*—Pipe shall be acceptable under the strength test requirements when all test specimens conform to the test requirements. Should any of the test specimens fail to meet the test requirements, then the manufacturer will be allowed a retest on two additional specimens for each specimen that failed, and the pipe shall be acceptable only when all of the retest specimens meet the strength requirements.

(*b*) *Acceptance or Rejection as to Other Than Strength Properties.*—In other than strength tests when not more than 20 per cent of the specimens fail to pass the requirements of the specification, the manufacturer may cull his stock and may eliminate whatever quantity of pipe he desires and must so mark those pipe that they will not be shipped. The required tests shall be made on the balance of the order and they shall be accepted if they conform to the test requirements.

Section 30.—Redesignate present Paragraph "(*c*)" as "(*d*)," and add the following new Paragraph (*c*):

(*c*) Variations in laying lengths of two opposite sides of a pipe shall be not more than ⅛ in. per ft of diameter with a maximum of ⅝ in. in any length of pipe.

Section 31.—Change the second sentence to read: "The planes of the ends of the pipe shall be perpendicular to their longitudinal axes subject to limits of variation in Section 30 (*c*)."

Table I.—Remove the Note which appears at the top of Table I.

Add the following sentence to footnote (*a*) of Table I: "Where two lines of circular steel are specified, the inner cage shall contain not less than 50 per cent nor more than 60 per cent of the total area of steel listed above for each size of pipe."

Figure 2.—Revise Fig. 2 as recommended for Fig. 1 of Standard Specifications C 14 above.

Figure 3.—Revise Fig. 3 to show an I-beam in both the cross-sectional view and the end view on top of the wooden bearing block. The I-beam shall be labeled "Rigid steel member, I-beam or other type."

Standard Specifications for Reinforced-Concrete Culvert Pipe (**C 76 - 52**):[1]

Section 21.—Change this section to read as recommended for Section 20 of Standard Specifications C 75 above.

Section 27.—Change this section to read as recommended for Section 25 of Standard Specifications C 75.

Section 32.—Redesignate present Paragraph "(*c*)" as "(*d*)" and add a new Paragraph (*c*) as recommended for

Section 30 of Standard Specifications C 75.

Section 33.—Change the second sentence to read: "The planes of the ends of the pipe shall be perpendicular to their longitudinal axes subject to limits of variation in Section 32 (*c*)."

Table I and Table II.—Revise as follows: Under the columns headed "Circular Reinforcement in Circular Pipe," change the word "each" to "totaling," and double the numerical value of each number following the present word "each." Add a footnote (*c*) as follows: "Where two lines of circular steel are specified, the inner cage shall contain not less than 50 per cent nor more than 60 per cent of the total area of steel listed above for each size of pipe." The reference to this footnote shall follow the word "lines" each place the word appears under the column headed "Circular Reinforcement in Circular Pipe."

Figure 2.—Revise Fig. 2 as recommended for Fig. 1 of Standard Specifications C 14 above.

Figure 3.—Revise Fig. 3 as recommended for Fig. 3 of Standard Specifications C 75 above.

Standard Specifications for Concrete Irrigation Pipe (**C 118 - 52**):[1]

Title.—Change the title of the specification to read "Standard Specifications for Concrete Pipe for Irrigation or Drainage."

Section 1.—Add the words "and for use in drainage."

Section 2.—Add the words "or as 'ASTM Standard Concrete Drainage Pipe'."

Section 5.—Add a footnote as follows: "Where alkali or sulfates are present, sulfate-resistant cement shall be used in manufacturing, and the maximum allowable absorption shall be 5 per cent.

Section 11.—Change to read as follows:

11. (*a*) When used for irrigation systems, the ends of the pipe shall be so formed that when laid together and the joints cemented, they will make a continuous and uniform line of pipe with a smooth and regular interior surface. The joints shall be of such design as will permit effective cementing and placement without appreciable irregularities in the flow line.

(*b*) When used for drainage, joints shall be furnished which will preserve alignment in the trench when laid without mortar or other jointing material, allow the entrance of water, and minimize the entrance of solids.

Section 12.—Change Paragraphs (*d*) and (*e*) to read as recommended for Section 25, Paragraphs (*a*) and (*b*) of Standard Specifications C 75 above.

Table I.—Change the title to read as follows: "Physical Test Requirements for Standard Concrete Irrigation Pipe and Standard Concrete Drainage Pipe."

Table I.—Add the following new pipe sizes and test requirements for these sizes of pipe:

Internal Diameter, in.	Minimum Shell Thickness, in.	Test Requirements		
		Internal Hydrostatic Pressure on Individual Sections, psi	Minimum Three-Edge-Bearing Load, lb per linear ft	Maximum Absorption, per cent
4.......	¾	75	1000	8
*5......	¾	75	1000	8

* Special sizes obtainable in some localities.

Figure 1.—Revise Fig. 1 as recommended for Fig. 3 of Standard Specifications C 75 above.

ADOPTION OF TENTATIVE REVISIONS AS STANDARD

The committee recommends that the tentative revisions of the following standards as indicated be approved for reference to letter ballot of the Society for adoption as standard:

Standard Specifications for Concrete Sewer Pipe (**C 14 - 52**),[1] tentative revision of Section 10 (*b*), issued June, 1951.

labeled "Rigid steel member, I-beam or other type."

Standard Specifications for Reinforced Concrete Sewer Pipe (**C 75 – 52**):[1]

Section 20.—Change to read as follows:

20. A purchaser of pipe, whose needs require shipments at intervals over extended periods of time, shall be entitled to preliminary tests of not more than three sections of pipe covering each size in which he is interested. Pipe having a diameter greater than 72 in. shall be accepted on the basis of tests of absorption and compressive strength of concrete cores drilled from the barrel of the pipe, and by examination of the quality, amount, and accuracy of placement of the reinforcement. When mutually agreed upon by the purchaser and the seller, pipe having an internal diameter of 72 in. and less may also be accepted on the basis of tests of strength and absorption of drilled cores, in which case the specified strength requirements for full size pipe shall be waived. Cores drilled from the barrel of the pipe shall have a diameter not less than 3½ in. They shall be secured, prepared for testing, and tested by the methods prescribed in Standard Methods of Securing, Preparing and Testing Specimens from Hardened Concrete for Compressive and Flexural Strength (ASTM Designation: C 42).

When the cores cut from a section of pipe successfully meet the strength test requirement, the core-holes shall be plugged and sealed by the manufacturer in such a manner that the pipe section will meet all of the test requirements of this specification. Pipe sections, so sealed, shall be considered as satisfactory for use.

After these preliminary tests, a purchaser shall be entitled to additional tests in such numbers and at such times as he may deem necessary, provided that the total number of pipe tested shall not exceed 1 per cent of the pipe delivered.

Section 25.—Change to read as follows:

25 (*a*). *Acceptance or Rejection as to Strength Properties.*—Pipe shall be acceptable under the strength test requirements when all test specimens conform to the test requirements. Should any of the test specimens fail to meet the test requirements, then the manufacturer will be allowed a retest on two additional specimens for each specimen that failed, and the pipe shall be acceptable only when all of the retest specimens meet the strength requirements.

(*b*) *Acceptance or Rejection as to Other Than Strength Properties.*—In other than strength tests when not more than 20 per cent of the specimens fail to pass the requirements of the specification, the manufacturer may cull his stock and may eliminate whatever quantity of pipe he desires and must so mark those pipe that they will not be shipped. The required tests shall be made on the balance of the order and they shall be accepted if they conform to the test requirements.

Section 30.—Redesignate present Paragraph "(*c*)" as "(*d*)," and add the following new Paragraph (*c*):

(*c*) Variations in laying lengths of two opposite sides of a pipe shall be not more than ⅛ in. per ft of diameter with a maximum of ⅝ in. in any length of pipe.

Section 31.—Change the second sentence to read: "The planes of the ends of the pipe shall be perpendicular to their longitudinal axes subject to limits of variation in Section 30 (*c*)."

Table I.—Remove the Note which appears at the top of Table I.

Add the following sentence to footnote (*a*) of Table I: "Where two lines of circular steel are specified, the inner cage shall contain not less than 50 per cent nor more than 60 per cent of the total area of steel listed above for each size of pipe."

Figure 2.—Revise Fig. 2 as recommended for Fig. 1 of Standard Specifications C 14 above.

Figure 3.—Revise Fig. 3 to show an I-beam in both the cross-sectional view and the end view on top of the wooden bearing block. The I-beam shall be labeled "Rigid steel member, I-beam or other type."

Standard Specifications for Reinforced-Concrete Culvert Pipe (**C 76 – 52**):[1]

Section 21.—Change this section to read as recommended for Section 20 of Standard Specifications C 75 above.

Section 27.—Change this section to read as recommended for Section 25 of Standard Specifications C 75.

Section 32.—Redesignate present Paragraph "(*c*)" as "(*d*)" and add a new Paragraph (*c*) as recommended for

Section 30 of Standard Specifications C 75.

Section 33.—Change the second sentence to read: "The planes of the ends of the pipe shall be perpendicular to their longitudinal axes subject to limits of variation in Section 32 (*c*)."

Table I and Table II.—Revise as follows: Under the columns headed "Circular Reinforcement in Circular Pipe," change the word "each" to "totaling," and double the numerical value of each number following the present word "each." Add a footnote (*c*) as follows: "Where two lines of circular steel are specified, the inner cage shall contain not less than 50 per cent nor more than 60 per cent of the total area of steel listed above for each size of pipe." The reference to this footnote shall follow the word "lines" each place the word appears under the column headed "Circular Reinforcement in Circular Pipe."

Figure 2.—Revise Fig. 2 as recommended for Fig. 1 of Standard Specifications C 14 above.

Figure 3.—Revise Fig. 3 as recommended for Fig. 3 of Standard Specifications C 75 above.

Standard Specifications for Concrete Irrigation Pipe (**C 118 - 52**):[1]

Title.—Change the title of the specification to read "Standard Specifications for Concrete Pipe for Irrigation or Drainage."

Section 1.—Add the words "and for use in drainage."

Section 2.—Add the words "or as 'ASTM Standard Concrete Drainage Pipe'."

Section 5.—Add a footnote as follows: "Where alkali or sulfates are present, sulfate-resistant cement shall be used in manufacturing, and the maximum allowable absorption shall be 5 per cent.

Section 11.—Change to read as follows:

11. (*a*) When used for irrigation systems, the ends of the pipe shall be so formed that when laid together and the joints cemented, they will make a continuous and uniform line of pipe with a smooth and regular interior surface. The joints shall be of such design as will permit effective cementing and placement without appreciable irregularities in the flow line.

(*b*) When used for drainage, joints shall be furnished which will preserve alignment in the trench when laid without mortar or other jointing material, allow the entrance of water, and minimize the entrance of solids.

Section 12.—Change Paragraphs (*d*) and (*e*) to read as recommended for Section 25, Paragraphs (*a*) and (*b*) of Standard Specifications C 75 above.

Table I.—Change the title to read as follows: "Physical Test Requirements for Standard Concrete Irrigation Pipe and Standard Concrete Drainage Pipe."

Table I.—Add the following new pipe sizes and test requirements for these sizes of pipe:

Internal Diameter, in.	Minimum Shell Thickness, in.	Test Requirements		
		Internal Hydrostatic Pressure on Individual Sections, psi	Minimum Three-Edge-Bearing Load, lb per linear ft	Maximum Absorption, per cent
4.......	¾	75	1000	8
*5......	¾	75	1000	8

* Special sizes obtainable in some localities.

Figure 1.—Revise Fig. 1 as recommended for Fig. 3 of Standard Specifications C 75 above.

ADOPTION OF TENTATIVE REVISIONS AS STANDARD

The committee recommends that the tentative revisions of the following standards as indicated be approved for reference to letter ballot of the Society for adoption as standard:

Standard Specifications for Concrete Sewer Pipe (**C 14 - 52**),[1] tentative revision of Section 10 (*b*), issued June, 1951.

Standard Specifications for Reinforced Concrete Sewer Pipe (**C 75 – 52**),[1] tentative revision of Section 30 (*b*) issued June, 1951.

Standard Specifications for Reinforced Concrete Culvert Pipe (**C 76 – 52**),[1] tentative revision of Section 32 (*b*) issued June, 1951.

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[2]

SUBCOMMITTEE ACTIVITIES

Long Range Planning Subcommittee (W. E. Corbett, chairman).—This subcommittee is continuing its consideration of interim matters which are presented between meetings of the committee.

The Task Group on Specifications for Low-Head Pressure Concrete Pipe (H. G. Curtis, chairman) has under development proposed specifications for low-head reinforced-concrete pressure pipe, and for low-head reinforced-concrete sewage force mains.

A task group under the chairmanship of Peter Van Kuran has been appointed to study the need for a specification for precast concrete manholes for access to nonpressure lines.

A task group has been appointed under the chairmanship of M. G. Spangler to study the desirability of combining Specifications C 75 and C 76, or to coordinate them and bring them up to date in accordance with present practices and wording.

This report has been submitted to letter ballot of the committee, which consists of 36 members; 28 members returned their ballots, of whom 27 have voted affirmatively and 1 negatively.

Respectfully submitted on behalf of the committee,

R. R. LITEHISER,
Chairman.

HOWARD F. PECKWORTH,
Secretary.

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[2] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

REPORT OF COMMITTEE C-14

ON

GLASS AND GLASS PRODUCTS*

Committee C-14 on Glass and Glass Products held two meetings during the past year: on October 8, 1953, in Rochester, N. Y., and on April 21, 1954, in Chicago, Ill.

During the year there have been two resignations, and three new members have been added to the committee.

The committee, as of April 21, consisted of 47 voting members, 9 nonvoting members, and 15 consulting members. The voting membership consists of 17 producers, 16 consumers, and 14 general interest members.

The present officers were re-elected for the ensuing term of two years.

RECOMMENDATIONS ACCEPTED BY THE ADMINISTRATIVE COMMITTEE ON STANDARDS

Subsequent to the 1953 Annual Meeting, Committee C-14 presented to the Society through the Administrative Committee on Standards the following recommendations:

Tentative Methods for:

Determining Annealing and Strain Points of Glass (C 336 – 54 T),

Determining the Softening Point of Glass (C 338 – 54 T), and

Determining Average Linear Expansion of Glass (C 337 – 54 T).

Revision of Tentative Methods of:

Sampling and Testing Structural Non-Load Bearing Cellular Glass Blocks (C 240 – 50 T).

These recommendations were accepted by the Standards Committee on May 18, 1954.

ADOPTION OF TENTATIVE AS STANDARD

The committee recommends that the Tentative Methods of Test for Resistance of Glass Containers to Chemical Attack (**C 225 – 49 T**)[1] be approved for reference to letter ballot of the Society for adoption as standard without change.

ACTIVITIES OF SUBCOMMITTEES

Subcommittee II on Chemical Analysis (F. W. Glaze, chairman) is preparing revisions of the Methods of Chemical Analysis of Glass Sand (C 146 – 43) and the Methods of Chemical Analysis of Soda-Lime Glass (C 169 – 53). The subcommittee is also working on colorimetric procedures for determining aluminum oxide, titanium dioxide, chromic oxide, and ferric oxide.

Subcommittee IV on Physical and Mechanical Properties (H. R. Lillie, chairman) has prepared methods for the determination of softening point, thermal expansion, strain, and annealing points, and these methods are being presented to the Administrative Committee on Standards as stated previously in the report.

Subcommittee VI on Glass Construction Block and Tile (A. H. Baker, chairman). —A revision of the Tentative Methods of Sampling and Testing Structural Non-Load-Bearing Cellular Glass Blocks

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13–18, 1954.

[1] 1952 Book of ASTM Standards Part 3.

(C 240 – 50 T) has been prepared by the subcommittee, and is being presented to the Administrative Committee on Standards.

This report has been submitted to letter ballot of the committee, which consists of 47 voting members; 33 members returned their ballots, of whom 31 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

L. G. GHERING,
Chairman.

F. V. TOOLEY,
Secretary.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee C-14 presented to the Society through the Administrative Committee on Standards tentative revisions of the Standard Definitions of Terms Relating to Glass and Glass Products (C 162 – 52). The tentative revisions were accepted by the Standards Committee on December 22, 1954, and they will appear in the April, 1955, Compilation of ASTM Standards on Glass and Glass Products.

REPORT OF COMMITTEE C-15

ON

MANUFACTURED MASONRY UNITS*

Committee C-15 on Manufactured Masonry Units held two meetings during the past year: on July 2, 1953 in Atlantic City, N. J., in connection with the Annual Meeting of the Society, and on February 2, 1954, in Washington, D. C., during ASTM Committee Week.

At the present time Committee C-15 consists of 65 members, of whom 30 are classified as producers, 18 as consumers, and 17 as general interest members.

Committee C-15 has voted to expand its scope to include waterproofing materials for unit masonry. A special study committee has been appointed to recommend qualified and interested people for membership on a new subcommittee for such materials.

Subcommittees II on Clay Building Brick, IV on Paving and Sewer Brick, and VII on Structural Clay Tile have been combined and will bear the title of Subcommittee II on Clay Brick and Structural Clay Tile.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, J. W. Whittemore.

First Vice-Chairman, Theodore I. Coe.

Second Vice-Chairman, P. M. Woodworth.

Secretary, M. H. Allen.

RECOMMENDATIONS ACCEPTED BY THE ADMINISTRATIVE COMMITTEE ON STANDARDS

Subsequent to the Annual Meeting, Committee C-15 presented to the Society through the Administrative Committee on Standards the following recommendation:

Tentative Revision of Standard:

Specifications for Structural Clay Load-Bearing Wall Tile (C 34 - 52).

This recommendation was accepted by the Standards Committee on September 9, 1953, and the tentative revision appears in the 1953 Supplement to Book of ASTM Standards, Part 3.

TENTATIVE REVISION OF STANDARD

The committee recommends for publication the following tentative revision of Standard Methods of Sampling and Testing Concrete Masonry Units (**C 140 - 52**):[1]

Section 7.—Change to read as follows:

7. The units shall be prepared by one of two capping procedures:

(*a*) *Cement-Gypsum Capping.*—A quantity of plastic capping mortar, made of one part (by volume) of portland cement and one part of calcined gypsum (plaster of Paris) and mixed with sufficient water to spread evenly, shall be placed on a nonabsorbent surface which has been coated with oil. The surface shall be plane within 0.003 in. in 16 in. and shall be sufficiently rigid and so supported as not to be measurably deflected during the capping operation. The surface of the unit to be capped shall be placed on the capping mortar, and the specimen, held so that its axis is at right angles to the capping surface, shall be firmly pressed down with a single motion. The average thickness of the cap shall be not more than ⅛ in. Patching of the caps shall not be permitted. Imperfect caps shall be removed and replaced with new ones. The caps shall be aged for at least 24 hr before the specimens are tested.

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13–18, 1954.

[1] 1952 Book of ASTM Standards, Part 3.

(*b*) *Sulfur-Filler Capping.*—A mixture of 40 to 60 per cent sulfur (by weight), the remainder being ground fire clay or other suitable inert material passing a No. 100 (149 micron) sieve, with or without a plasticizer, shall be employed. The casting surface plate shall conform to the requirements described in 7(*a*) and shall be lightly coated with oil. Four 1 in. sq steel bars shall be placed on the surface plate to form a rectangular mold approximately ½ in. greater in either inside dimension than the masonry unit. The sulfur mixture shall be heated in a thermostatically controlled heating pot to a temperature sufficient to maintain fluidity for a reasonable period of time after contact with the capping surface. Care shall be exercised to prevent overheating, and the liquid shall be stirred in the pot just before use. The mold shall be filled to a depth of ¼ in. with molten sulfur material. The surface of the unit to be capped shall be quickly placed in the liquid, and the specimen shall be held so that its axis is at right angles to the capping surface. The unit shall be allowed to remain undisturbed until solidification is complete. The caps shall be allowed to cool for a minimum of 2 hr before the specimens are tested.

ADOPTION OF TENTATIVES AS STANDARD

The committee recommends that the following tentative specifications be approved without revision for reference to letter ballot of the Society for adoption as standard:

Tentative Specifications for:

Structural Clay Facing Tile (**C 212 – 52 T**),[1] and

Chemical-Resistant Masonry Units (**C 279 – 52 T**).[1]

TENTATIVES CONTINUED WITHOUT REVISION

The committee recommends that the Tentative Specifications for Drain Tile (**C 4 – 50 T**) which have stood without revision for two or more years, due to further revisions in process, be retained as tentative.[2]

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[3]

This report has been submitted to letter ballot of the committee, which consists of 65 members; 57 members have returned their ballots, of whom 56 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

J. W. WHITTEMORE,
Chairman.

M. H. ALLEN,
Secretary.

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[2] See Editorial Note, this page.

[3] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee C-15 presented to the Society through the Administrative Committee on Standards the recommendation that the Tentative Specifications for Drain Tile (C 4 – 50 T) be revised. The recommendation was accepted by the Standards Committee on September 28, 1954, and the revised specifications appear in the 1954 Supplement to Book of ASTM Standards, Part 3.

REPORT OF COMMITTEE C-16

ON

THERMAL INSULATING MATERIALS*

Committee C-16 on Thermal Insulating Materials and its subcommittees held two meetings during the past year: at Williamsburg, Va., on October 26, 27, and 28, 1953, and at Washington, D. C., on February 3, 4, and 5, 1954.

The committee consists of 73 voting members, 25 nonvoting members, 2 honorary members, 2 associate members, and 1 consulting member. The voting membership is classified as follows: 37 producers, 18 consumers, and 18 general interest members.

The Board of Directors approved an extension in scope for Committee C-16 to cover protective coatings used in connection with insulating materials. The revised scope reads as follows:

> "Formulation of test methods and specifications relating to thermal insulating materials (except those used in the insulating refactory field) and any protective coating material associated therewith to preserve their thermal insulating efficiency."

A new subcommittee was formed and designated Subcommittee T-X on Physical Properties (Other than Permeance) of Coatings Accessory to Thermal Insulation. Mr. H. E. Rapp was appointed chairman of this new subcommittee.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, E. R. Queer.
Vice-Chairman, W. H. Zane.
Vice-Chairman, W. L. Scott.
Secretary, W. L. Gantz.
Assistant Secretary, J. M. High.
Assistant Secretary (Membership), E. C. Shuman.

RECOMMENDATIONS ACCEPTED BY THE ADMINISTRATIVE COMMITTEE ON STANDARDS

Subsequent to the 1953 Annual Meeting, Committee C-16 presented to the Society through the Administrative Committee on Standards the following recommendations:

Tentative Specifications for:

85 per cent Magnesia Thermal Block Insulation (C 319 - 53 T),
85 per cent Magnesia Thermal Pipe Insulation (C 320 - 53 T),
Diatomaceous Earth Thermal Block Insulation (C 333 - 54 T), and
Diatomaceous Earth Thermal Pipe Insulation (C 334 - 54 T).

Tentative Method of Test for:

Thermal Conductivity of Pipe Insulation (C 335 - 54 T).

Revision of Tentative Method of Test for:

Thermal Conductance and Transmittance of Built-up Sections by Means of the Guarded Hot Box (C 236 - 49 T).

Tentative Revision of Standard Definitions of:

Terms Relating to Thermal Insulating Materials (C 168 - 51).

Tentative Specifications C 319 and C 320 were accepted by the Standards Committee on November 9, 1953, and the tentative revision of Standard Definitions C 168 was accepted on September 9, 1953. They appear in the 1953 Supplement to Book of ASTM Standards, Part 3.

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13-18, 1954.

Tentative Specifications C 333 and C 334 were accepted by the Standards Committee on January 13, 1954, and are appended hereto.[1] Tentative Method C 335 and the revision of Tentative Method C 236 were accepted on February 23, 1954, and will appear in the 1954 Supplement to Book of ASTM Standards, Part 3.

NEW TENTATIVES

The committee recommends that the following specifications be accepted for publication as tentatives as appended hereto:[1]

Tentative Specifications for:

Cellular Glass Insulating Block,
Calcium Silicate Thermal Block Insulation, and
Calcium Silicate Thermal Pipe Insulation.

ADOPTION OF TENTATIVES AS STANDARD

The committee recommends that the following tentative specifications be approved for reference to letter ballot of the Society for adoption as standard:

Tentative Specifications for:

Mineral Wool Blanket Insulation (Metal-Mesh Covered) (Industrial Type) (**C 263 – 51 T**),[2] and
Mineral Wool Blanket-Type Pipe Insulation (**C 280 – 51 T**).[2]

ADOPTION OF TENTATIVE REVISION AS STANDARD

The committee recommends that the tentative revision of Standard Method of Test for Compressive Strength of Preformed Block Type Thermal Insulation (C 165 – 45)[2] issued June, 1952,[2] be approved for reference to letter ballot of the Society for adoption as standard.

WITHDRAWAL OF TENTATIVE

The committee recommends withdrawal of the Tentative Methods of Test for Water Vapor Permeability of Sheet Materials Used in Connection with Thermal Insulation (**C 214 – 48 T**).[2] Withdrawal is recommended on the basis that the same method is covered in the Tentative Methods of Test for Measuring Water Vapor Transmission of Materials in Sheet Form (E 96 – 53 T).[3]

TENTATIVES CONTINUED WITHOUT REVISION

The committee recommends that the following tentatives which have stood without revision for two or more years be retained as tentative:

Tentative Specification for:

Mineral Wool Molded Type Pipe Insulation (for Elevated Temperatures) (C 281 – 52 T),
Cellular Asbestos Paper Thermal Insulation for Pipes (C 298 – 52 T),
Laminated Asbestos Thermal Insulation for Pipes (C 299 – 52 T),
Mineral Wool Pipe Insulation; Molded Type (Low Temperatures) (C 300 – 52 T),
Mineral Wool Batt Insulation (Industrial Type) (C 262 – 51 T), and
Mineral Wool Felt Insulation (Industrial Type) (C 264 – 51 T).

Tentative Method of Test for:

Density of Preformed Pipe Covering Type Thermal Insulation (C 302 – 52 T),
Density of Preformed Block Type Thermal Insulation (C 303 – 52 T), and
Vibration Resistance of Preformed Thermal Insulation for Pipes (C 304 – 52 T).

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[1] The new tentatives were accepted by the Society and appear in the 1954 Supplement to Book of ASTM Standards, Part 3.

[2] 1952 Book of ASTM Standards, Part 3.

[3] 1953 Supplement to Book of ASTM Standards, Part 7.

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[4]

This report has been submitted to letter ballot of the committee, which consists of 73 voting members, of whom 33 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

E. R. QUEER,
Chairman.

W. L. GANTZ,
Secretary.

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[4] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee C-16 presented to the Society through the Administrative Committee on Standards the following recommendations:

Tentative Specification for:

Corkboard Thermal Insulation (C 352 - 54 T).

Tentative Method of Test for:

Mean Specific Heat of Thermal Insulation (C 351 - 54 T),
Adhesion of Dried Thermal Insulating Cements (C 353 - 54 T),
Compressive Strength of Thermal Insulating Cement (C 354 - 54 T), and
Water Vapor Transmission of Materials Used in Building Construction (C 355 - 54 T).

Tentative Method C 351 was accepted by the Standards Committee on October 4, 1954, and appears in the 1954 Supplement to Book of ASTM Standards, Part 3; the remaining recommendations were accepted on December 22, 1954, and are available as separates.

REPORT OF COMMITTEE C-21
ON
CERAMIC WHITEWARE*

Committee C-21 on Ceramic Whiteware held two meetings during the year: the first in Bedford Springs, Pa., on October 1, 1953, and the second in Chicago, Ill., on April 20, 1954. The Executive Subcommittee met on the same days. The present voting membership consists of 43 producers, 10 consumers, and 18 general interest, or a total of 71.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, C. J. Koenig.
Vice-Chairman, G. W. Phelps.
Secretary, A. J. Gitter.

RECOMMENDATIONS ACCEPTED BY THE ADMINISTRATIVE COMMITTEE ON STANDARDS

Subsequent to the 1953 Annual Meeting, Committee C-21 presented to the Society through the Administrative Committee on Standards the following recommendations:

Tentative Method of:

Sampling Whiteware Clays (C 322 – 53 T),
Chemical Analysis of Whiteware Clays (C 323 – 53 T),
Test for Free Moisture Content of Whiteware Clays (C 324 – 53 T),
Test for Wet Sieve Analysis of Whiteware Clays (C 325 – 53 T),
Test for Drying and Firing Shrinkages of Whiteware Clays (C 326 – 53 T),
Test for Linear Thermal Expansion by the Interferometric Method (C 327 – 53 T),
Test for Modulus of Rupture of Fired Dry-Pressed Whiteware Specimens at Normal Temperature (C 328 – 53 T), and
Test for True Specific Gravity of Fired Whiteware Materials (C 329 – 53 T).

Tentative Method C 323 was accepted by the Standards Committee on January 13, 1954, and the other methods were accepted on December 16, 1953; they all appear in the 1953 Supplement to Book of ASTM Standards, Part 3.

REVISION OF TENTATIVES

Tentative Definitions of Terms Relating to Ceramic Whiteware **(C 242 – 50 T)**.[1]—Committee C-21 recommends the revision of these definitions as appended hereto.[2] The revision consists of the addition of new definitions and the revision of definitions currently published.[1]

This recommendation has been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[3]

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Nomenclature (A. S. Watts, chairman).—This group held several meetings during the year and succeeded in processing to the stage of submission as tentatives the considerable modification and amplification of

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13–18, 1954.

[1] 1952 Book of ASTM Standards, Part 3.

[2] The revised tentative was accepted by the Society and appears in the 1954 Supplement to Book of ASTM Standards, Part 3.

[3] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

C 242 - 50 T referred to above. They also have developed and have submitted to ballot within the subcommittee twelve additional definitions of terms relating to ceramic whiteware.

Subcommittee II on Tests and Specifications (Van E. Campbell, chairman).—Five methods of test, noted earlier in this report, originating in Subsection A1 on Clays under the chairmanship of G. W. Phelps, have been accepted as tentative by the Standards Committee during the year.

The Group on Titanates and Zirconates (W. J. Baldwin, chairman) held one meeting at which was considered the problem involved in evaluating ceramic and electrical properties of barium titanate dielectrics. To determine the effect of variations in the firing and silvering operations, specimens were submitted to ten cooperating laboratories.

Subsection C1 on Fundamental Properties (W. C. Mohr, chairman) is directly responsible for three test methods referred to earlier in this report, which were accepted as tentative by the Standards Committee during the year. This subsection has currently under consideration four additional test procedures.

Subcommittee III on Research (H. Z. Schofield, chairman).—The activities of this subcommittee have been concerned primarily in originating and promoting research. During the past year these activities have related primarily to the subsieve particle size studies, under the direct supervision of Kent Smalley, and to re-evaluating methods for modulus of rupture determinations.

This report has been submitted to letter ballot of the committee which consists of 71 voting members; 60 members returned their ballots, of whom 59 voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

C. G. Harman,
Chairman.

R. F. Geller,
Secretary

REPORT OF COMMITTEE C-22
ON
PORCELAIN ENAMEL*

Committee C-22 on Porcelain Enamel held three meetings during the year: in Atlantic City, N. J., on July 1, 2, and 3, 1953, during the Annual Meeting of the Society; in Middletown, Ohio, on October 27 and 28, 1953; and in Washington, D. C., on February 2 and 3, 1954, during ASTM Committee Week.

During the past year four new members have been added to the committee and there have been two resignations. At the same time, two corporate member representatives have been replaced. At the present time the committee consists of 41 members, of whom 35 are voting members, with 20 classified as producers, 6 as consumers, and 9 as general interest.

During the year the committee has added one new subcommittee to its organization, namely, Subcommittee IV on Education.

Election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, W. N. Harrison.
Vice-Chairman, D. G. Bennett.
Secretary, G. H. Spencer-Strong.
Members of Executive Subcommittee at Large, B. J. Sweo, J. T. Roberts.

NEW TENTATIVES

The committee recommends that the following two methods be accepted for publication as tentative as appended hereto:[1]

Tentative Methods of Test for:

45-deg Specular Gloss of Porcelain Enamels, and
Reflectivity and Coefficient of Scatter of White Porcelain Enamels.

ADOPTION OF TENTATIVES AS STANDARDS

The committee recommends that the Tentative Method of Test for Resistance of Porcelain Enameled Utensils to Boiling Acid (**C 283 – 51 T**)[2] and the Tentative Method of Test for Sieve Analysis of Wet Milled and Dry Milled Porcelain Enamel (**C 285 – 52 T**)[2] be approved without change for reference to letter ballot of the Society for adoption as standard.

TENTATIVES CONTINUED WITHOUT REVISION

The committee recommends that the following be continued as tentative without revision:

Tentative Method of Test for:

Impact Resistance of Porcelain Enameled Utensils (C 284 – 51 T).

Tentative Definitions of:

Terms Relating to Porcelain Enamel (C 286 – 51 T).

The recommendations appearing in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[3]

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13–18, 1954.

[1] The new tentatives were accepted by the Society and appear in the 1954 Supplement to Book of ASTM Standards, Part 3.

[2] 1952 Book of ASTM Standards, Part 2.

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Research (J. J. Canfield, chairman) has eight problems under investigation. Bibliographies have been prepared on two of these: (1) the long- and short-term effects of porcelain enamel coatings on fatigue of metals and (2) spontaneous chipping and spalling of porcelain enamel coatings. The bibliographies on two other projects are almost completed. Work on the review of existing test methods on these four projects is under way.

Subcommittee II on Nomenclature (E. E. Howe, chairman) is working on a review of the Tentative Definition of Terms Relating to Porcelain Enamel (C 286 – 51 T) with the view of increasing the scope and general usefulness of the definitions.

Subcommittee III on Tests and Specifications (R. F. Bisbee, chairman):

Sections 1 and 2 on Raw Materials and Materials in Process (W. A. Deringer, chairman) are carrying on the development of tentative tests for torsion, tearing, evaluation of enameling iron, coefficient of expansion, consistency of enamel slip, fusibility, and the evaluation of certain characteristics of clays. A suggested tentative classification of water used in the milling of porcelain enamel has been prepared for distribution to Subcommittee III members for comment. The sections have also undertaken a study of methods for the disposal of enamel plant wastes.

Section 3 on Finished Products (J. H. Gregory, chairman) is working on nine suggested test methods including methods for the evaluation of abrasion resistance, thickness, thermal shock resistance, chemical resistance, scratch resistance, continuity of coatings, metal marking resistance, impact resistance, and color and color difference determinations for porcelain enamels.

During the past year Subcommittee III has completed two proposed tentative methods of test which are included in the recommendations of this report.

This report was submitted to letter ballot of the committee, which consists of 35 voting members; 30 members returned their ballots, of whom 29 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

W. N. HARRISON,
Chairman.

G. H. SPENCER-STRONG,
Secretary.

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[3] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

REPORT OF COMMITTEE D-1

ON

PAINT, VARNISH, LACQUER, AND RELATED PRODUCTS*

Committee D-1 on Paint, Varnish, Lacquer, and Related Products held two meetings during the year: in Atlantic City, N. J., on June 29 to July 1, 1953, in connection with the 1953 Annual Meeting of the Society; and in Washington, D. C., on February 1 to 3, 1954, in connection with ASTM Group Committee Meetings.

At the June, 1953, meeting, H. C. Reed, Forbes Finishes Division, Pittsburgh Plate Glass Co., presented a paper on "Technical Responsibility to Management in the Paint, Varnish and Lacquer Industry." The paper considered not only the responsibilities of technical men in the industry but also the ways in which standard specifications and methods of test assist management.

At the February, 1954, meeting, Roger Saur, General Motors Corp., presented a well-illustrated talk on "Photochemical Deterioration of Automobile Lacquers." For the June, 1954, meeting, a companion paper is planned entitled "Photochemical Deterioration of Alkyd Enamels" by E. B. Fitzgerald, E. I. du Pont de Nemours and Co., Inc.

During the past year, a new Subcommittee on Methods of Test for Latex and Emulsion Paints has been organized under the chairmanship of P. T. Howard.

Committee D-1 has continued its close cooperation with the Federation of Paint and Varnish Production Clubs through the Joint Committee on Paint, Varnish, and Lacquer (F. M. Damitz, chairman). In the past year, the following ten ASTM methods have been approved by the Standards and Methods of Tests Committee of the Federation and will be assigned Federation numbers:

Methods of Chemical Analysis of White Pigments (D 34 - 51 T),
Method of Test for Water in Petroleum Products and Other Bituminous Materials (D 95 - 46),
Methods for Chemical Analysis of Yellow, Orange, and Green Pigments Containing Lead Chromate, and Chromium Oxide Green (D 126 - 50 T),
Methods of Test for Specific Gravity of Pigments (D 153 - 52 T),
Methods for Chemical Analysis of Blue Pigments (D 1135 - 50 T),
Methods of Test for Coarse Particles in Pigments, Pastes, and Paints (D 185 - 45),
Methods of Chemical Analysis of White Linseed Oil Paints (D 215 - 41),
Methods of Chemical Analysis of Zinc Yellow Pigment (Zinc Chromate Yellow) (D 444 - 51),
Methods of Testing Para Red and Toluidine Red Pigments (D 970 - 51), and
Method of Test for Oil Absorption of Pigments (D 281 - 31).

The number of standards which have been jointly approved by both organizations is now 61. There are ten additional ASTM standards and tentatives now being considered by the Federation. At the same time, two methods which originated with the Federation are being considered within Committee D-1. Both organizations are also continuing to cooperate in the preparation of specifications for mineral spirits.

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13-18, 1954.

The Committee on Inter-Committee Relations, composed of D-1 representatives on other ASTM technical committees, is continuing to maintain close contact with those committees whose activities are of interest to Committee D-1. In the last year, representatives of Committee D-1 have been appointed to the new Subcommittee on Microscopy of Committee E-1 on Methods of Testing, to Committee D-21 on Wax Polishes and Related Material, and to Committee E-11 on Quality Control of Materials.

Since the last report, the American Standards Association has approved as American Standards the following ASTM methods of test developed by Committee D-1:

Methods of Test for:

Specific Gravity of Pigments (D 153 - 52 T; ASA K41—1953), and

Mass Color and Tinting Strength of Color Pigments (D 387 - 52 T; ASA K57—1953).

Committee D-1 has submitted seven additional standards under its jurisdiction for approval by ASA as American Standards.

In the past year, Committee D-1 has sponsored the publication of two articles in the ASTM BULLETIN as follows:

"Tinting Strength of Opaque White Pigments," by L. A. Melsheimer (October, 1953).

"Development of a Hiding Power Test Method—Report of Progress," by M. H. Switzer (April, 1954).

Carlton H. Rose, a long-time member of Committee D-1, was given the ASTM Award of Merit by the Society at the June, 1953, Annual Meeting.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, W. T. Pearce.
Vice-Chairman, E. W. Fasig.
Secretary, W. A. Gloger.

RECOMMENDATIONS ACCEPTED BY THE ADMINISTRATIVE COMMITTEE ON STANDARDS

Subsequent to the 1953 Annual Meeting, Committee D-1 presented to the Society through the Administrative Committee on Standards the following recommendations:

Tentative Method of:

Test for Residual Odor of Lacquer Solvents and Diluents (D 1296 - 53 T), and

Test for No-Dirt-Retention Time of Traffic Paint (D 1297 - 53 T).

Chemical Analysis of White Pigments (D 1301 - 53 T).

These recommendations were accepted by the Standards Committee on September 9, 1953, and the new methods appear in the 1953 Supplement to Book of ASTM Standards, Part 4.

PROPOSED SPECIFICATIONS TO BE PUBLISHED AS INFORMATION

The committee recommends for publication as information the Proposed Specifications for Raw Safflower Oil as appended hereto.[1]

NEW TENTATIVES

The committee recommends for publication as tentative the following seven methods of test:

Tentative Methods of:

Test for Viscosity Reduction Power of Hydrocarbon Solvents, as published in 1953 as a proposed method,[2]

Test for Apparent Free Phenols in Synthetic Phenolic Resins or Solutions Used for Coating Purposes,[3]

Test for Acid Number of Bleached Lac and Bleached Lac Varnish,[3]

Test for Fineness of Grind of Printing Inks by the Production Grindometer,[3]

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[1] This method appears in the January, 1955, Compilation on Paint, Varnish, Lacquer, and Related Products.

[2] *Proceedings*, Am. Soc. Testing Mats., Vol. 53, p. 342 (1953).

[3] The new tentatives were accepted by the Society and appear in the 1954 Supplement to Book of ASTM Standards, Part 4.

Test for Flash Point of Volatile Solvents by the Tag Open-Cup Apparatus published as information with the 1953 Report of Committee D-1,[4] with Section 7 on Precision revised to read as follows:

7. *Precision.*—For hydrocarbon solvents having flash points between 60 and 110 F, the repeatability is ±2 F, and the reproducibility is ±5 F.

Test for Phthalic Anhydride Content of Alkyd Resins and Esters Containing Other Dibasic Acids (Gravimetric),[3] and

Test for Phthalic Anhydride Content of Alkyd Resins and Esters Containing Other Dibasic Acids (Spectrophotometric).[3]

REVISION OF TENTATIVES

Committee D-1 recommends revisions of the following two methods and their continuation as tentative:

Tentative Method of Test for Kauri-Butanol Value of Hydrocarbon Solvents (**D 1133 - 50 T**):[5]

Section 5.—In Paragraph (*b*), delete the last sentence which reads: "The toluene factor is $\frac{105}{A}$."

In Paragraph (*c*), delete the last sentence which reads: "The blend factor is $\frac{40.0}{B}$."

Section 7.—Change Paragraph (*a*) to read as follows:

7. (*a*) Calculate the kauri-butanol value as follows:

$$\text{Kauri-butanol value} = \frac{65\,(C - B)}{A - B} + 40$$

where:

A = milliliters of toluene required to titrate 20 g of kauri-butanol reagent (Section 5 (*b*)),

B = milliliters of heptane-toluene blend required to titrate 20 g of kauri-butanol reagent (Section 5 (*c*)), and

C = milliliters of sample required to titrate 20 g of kauri-butanol reagent (Section 6).

Tentative Method of Test for Purity of Acetone and Methyl Ethyl Ketone (**D 1154 - 51 T**):[5]

Section 5.—Change Paragraph (*a*) to read as follows:

5. (a) *Alkaline Silver Reagent.*—Dissolve 9 ± 0.01 g of silver nitrate in distilled water; dilute to 100 ml and store in a dark bottle. Dissolve 9 ± 0.01 g of sodium hydroxide in distilled water; dilute to 100 ml and store in an alkaline resistant bottle. Immediately prior to use, prepare the alkaline silver reagent as follows: To 1 ml of the sodium hydroxide solution in a 10-ml graduated cylinder, add 1 ml of the silver nitrate solution. Dropwise add enough ammonium hydroxide (sp gr 0.90) to just dissolve the precipitate completely. If necessary, dilute with distilled water to exactly 3 ml.

Section 6.—Add the following Note to the end of Paragraph (*c*):

NOTE: *Caution.*—Decompose all residues and excess test solution immediately with excess dilute hydrochloric acid to avoid formation of unstable silver compounds. Do not stir the solution on addition or shake vigorously as fulminating silver may explode with violence in the liquid in which it is formed if the slightest stirring is used.

REVISION OF STANDARD, IMMEDIATE ADOPTION

The committee recommends for immediate adoption the following revision of the Standard Methods of Testing Drying Oils (**D 555 - 53**),[6] and accordingly asks for the necessary nine-tenths affirmative vote at the Annual Meeting in order that the revision may be referred to letter ballot of the Society:

Section 53.—Revise Paragraph (*c*) to read as follows:

(c) *Thermometer.*—An ASTM Low Distillation Thermometer graduated in centigrade degrees, having a range of 0 to 300 C, and conforming to the requirements for thermometer 7C-39 as prescribed in the Standard Specifications for ASTM Thermometers (ASTM Designation: E 1).

ADOPTION OF TENTATIVES AS STANDARD

Committee D-1 recommends that the following tentatives be approved for reference to letter ballot of the Society for adoption as standard without change:

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[4] *Proceedings*, Am. Soc. Testing Mats., Vol. 53, p. 344.

[5] 1952 Book of ASTM Standards, Part 4.

[6] 1953 Supplement to Book of ASTM Standards, Part 4.

Tentative Specifications for:

Methanol (Methyl Alcohol) (**D 1152 – 51 T**).[5]

Tentative Methods of:

Test for Specific Gravity of Pigments (**D 153 – 52 T**),[5]
Water Immersion Test of Organic Coatings on Steel (**D 870 – 51 T**),[5]
Laboratory Test for Degree of Resistance of Traffic Paint to Bleeding (**D 969 – 52 T**),[5]
Test for Viscosity of Paints, Varnishes, and Lacquers by Ford Viscosity Cup (**D 1200 – 52 T**),[5]
Test for Color of Clear Liquids (Platinum-Cobalt Scale) (**D 1209 – 52 T**),[5]
Test for Fineness of Dispersion of Pigment-Vehicle Systems (**D 1210 – 52 T**),[5]
Measurement of Wet Film Thickness of Paint, Varnish, Lacquer, and Related Products (**D 1212 – 52 T**),[5]
Test for Crushing Resistance of Glass Spheres (**D 1213 – 52 T**),[5] and
Test for Sieve Analysis of Glass Spheres (**D 1214 – 52 T**).[5]

REVISION OF STANDARD AND REVERSION TO TENTATIVE

The committee recommends that the Standard Method for Evaluating Resistance to Blistering of Paints on Metal When Subjected to Immersion or Other Exposure to Moisture or Liquids (**D 714 – 45**)[5] be revised as appended hereto[7] and reverted to tentative status. The revised method utilizes four sets of photographic reference standards to rate blistering as to size and frequency of blisters.

TENTATIVES CONTINUED WITHOUT REVISION

The committee recommends that the following tentatives be continued as tentative without revision:

Tentative Specifications for:

Heavy Petroleum Spirits (Heavy Mineral Spirits) (D 965 – 48 T),
Methyl Isobutyl Ketone (D 1153 – 51 T),
Asphalt-Base Emulsions for Use as Protective Coatings for Metal (D 1187 – 51 T),

Tentative Methods of:

Test for Ester Value of Tricresyl Phosphate (D 268 – 49 T),
Test for Mass Color and Tinting Strength of Color Pigments (D 387 – 52 T),
Testing Bituminous Emulsions for Use as Protective Coatings for Metal (D 1010 – 49 T), and

Tentative Recommended Practice for:

Operating Light and Water Exposure Apparatus (Carbon-Arc Type) for Testing Paint, Varnish, Lacquer, and Related Products (D 822 – 46 T).

The recommendations appearing in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[8]

ACTIVITIES OF SUBCOMMITTEES

Subcommittee II on Drying Oils (D. S. Bolley, chairman) prepared the proposed revision of the Methods of Testing Drying Oils (D 555 – 53) to restore the use of the original tung oil thermometer 7C-39 in place of the thermometer now specified. The subcommittee also recommended the publication as information only of the Proposed Specifications for Raw Safflower Oil. Revisions are being prepared of the Specifications for Oiticica Oil (Permanently Liquid) (D 601 – 46). The subcommittee is also working on determination of proper specification ranges for break on degummed soybean oil and the flash point of vegetable oils by the Pensky-Martens cup.

Subcommittee III on Bituminous Emulsions (R. H. Cubberley, chairman) is considering revisions of the Methods of Testing Bituminous Emulsions for Use as Protective Coatings for Metals (D 1010 – 49 T) in cooperation with

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[7] The revised method was accepted by the Society and appears in the 1954 Supplement to Book of ASTM Standards, Part 4.

[8] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

Committee D-8 on Bituminous Waterproofing and Roofing Materials.

Subcommittee IV on Traffic Paint (W. G. Vannoy, chairman) prepared the Tentative Method of Test for No-Dirt-Retention Time of Traffic Paint (D 1297 - 53 T), which was accepted by the Administrative Committee on Standards on September 9, 1953. It has also prepared a Proposed Tentative Method for Determining the Settling Properties of Traffic Paint During Storage and is completing a proposed method of test for no-smear-time of traffic paint. A revision of the Standard Method of Test for No-Pick-Up-Time of Traffic Paint (D 711 - 52) is also being prepared.

Subcommittee V on Volatile Solvents for Organic Protective Coatings (M. B. Chittick, chairman) prepared the proposed revision of the Tentative Method of Test for Kauri-Butanol Value of Hydrocarbon Solvents (D 1133 - 50 T) and also recommended acceptance as tentative of the Proposed Method of Test for Viscosity Reduction Power of Hydrocarbon Solvents which was published as information only in 1953.

Subcommittee VII on Accelerated Tests for Protective Coatings (H. D. Pharo, chairman) has recommended that the Tentative Methods of Water Immersion Test of Organic Coatings on Steel (D 870 - 51 T) be adopted as standard. It has prepared the proposed revision of Standard Method D 714 - 45, which revision includes a change to the shorter title of "Method for Evaluating Degree of Blistering of Paints." The subcommittee has undertaken a program of work to determine the effect of type of water used in the Tentative Recommended Practice for Operating Light and Water Exposure Apparatus (Carbon-Arc) (D 822 - 46 T). It is also working on the selection of suitable steel for use for panels.

Subcommittee VIII on Methods of Chemical Analysis of Paint Materials (W. H. Madson, chairman) prepared the Tentative Methods of Chemical Analysis of White Pigments (D 1301 - 53 T), which were accepted by the Administrative Committee on Standards on September 9, 1953. It is completing work on a proposed method for titanium dioxide analysis and a proposed revision of the Standard Methods of Chemical Analysis of Dry Mercuric Oxide (D 284 - 33). It is also undertaking revision of the method for the determination of nonvolatile content of paints and the preparation of a specific resistance method for the determination of soluble salts of iron oxide pigments.

Subcommittee IX on Varnish (J. C. Weaver, chairman) is continuing its cooperative work with Subcommittees X and XXV on the development of a suitable method for determination of gloss of dry transparent films. The subcommittee is continuing its work on acid value, abrasion resistance, and phthalic anhydride analysis.

Subcommittee X on Optical Properties (M. P. Morse, chairman) has active working groups engaged in developing methods for color difference measurement with the following instruments: Beckman Spectrophotometer, General Electric Spectrophotometer, Hunter Color Difference Meter, Color Eye, Color Master Colorimeter, and Photovolt. The subcommittee is continuing its work on hiding power, gloss and goniophotometry, gloss of clear coatings on wood, and tinting strength of white pigment.

Subcommittee XI on Resins (C. F. Pickett, chairman) prepared the proposed Tentative Method of Test for Apparent Free Phenols in Synthetic Phenolic Resins or Solutions Used for Coating Purposes, and also the two proposed Tentative Methods of Test for Phthalic Anhydride Content of Alkyd Resins and Esters Containing Other Dibasic Acids. The subcommittee is evaluating the foil method for determination of total solids of several types of resins and is continuing a round-robin on softening point of resins. Work on color formation when glycerine reacts with phthalic anhydride is continuing. The subcommittee has reviewed its accomplishments and realigned its objectives for future work in keeping with the present status and interests of the resin field.

Subcommittee XII on Methods of Test for Latex and Emulsion Paints (P. T. Howard, chairman) held its first meeting for the purpose of organizing its work and established working groups to study washability or scrubability, freeze-thaw stability, efflorescence, package stability, and other special methods for exterior emulsion paints.

Subcommittee XIII on Shellac (C. C. Hartman, chairman) prepared the proposed Tentative Method of Test for Acid Number of Bleached Lac and Bleached Lac Varnish. The subcommittee has continued its cooperative work with the International Organization for Standardization, Technical Committee 50 on Lac. It plans to develop a method for the determination of nonvolatile matter of lac resins soluble in alcohol, to revise the Specifications for Dry Bleached Shellac (D 207 - 49), to revise the Specifications for Orange Shellac and Other Lacs (D 237 - 48), and to develop a new method for determination of the color of lac resins.

Subcommittee XV on Specifications for Pigments Dry and in Oil (C. L. Crockett, chairman) is undertaking further work on the requirements for leafing properties of aluminum powder, on a method for evaluating the flocculation resistance and solvent stability of copper phthalocyanine blue pigments, and on the particle size characteristics of pigments. It has also organized a new group to produce numerical values for hues and shades of color.

Subcommittee XVI on Printing Inks (M C. Rogers, chairman) prepared the proposed Tentative Method of Test for Fineness of Grind of Printing Inks by the Production Grindometer. The subcommittee is continuing its work on the evaluation of printing inks for printability and on the rheological properties of inks.

Subcommittee XVII on Flash Point (A. L. Brown, chairman) has recommended publication as tentative of the Method of Test for Flash Point of Volatile Solvents by the Tag Open-Cup Apparatus as revised.[4] It will continue working towards obtaining greater precision in the method.

Subcommittee XVIII on Physical Properties of Materials (E. J. Dunn, Jr., chairman) is working on the relative oil absorption of pigments, the consistency of pastes, the hardness of organic coating films, water vapor permeability, fire retardancy, flow properties, the measurement of film thickness on nonmagnetic bases, and the consistency of paints. It has organized a new group to work on developing a method for determining the density of paint materials.

Subcommittee XXV on Cellulosic Coatings and Related Materials (F. H. Lang, chairman) prepared the proposed revision of the Methods of Test for Purity of Acetone and Methyl Ethyl Ketone (D 1154 - 51 T). The subcommittee also prepared the Tentative Method of Test for Residual Odor of Lacquer Solvents and Diluents (D 1296 - 53 T), which was accepted by the Administrative Committee on Standards on September 9, 1953. It also prepared a proposed Tentative Method of Test for Effect of Household Staining

Agents on Applied Nitrocellulose Clear and Pigmented Finishes which is being considered by the Administrative Committee on Standards. The subcommittee is continuing its work on the development of a test for failure of lacquer finishes on wood by checking due to moisture changes in the wood, and has organized a new group to develop a test for resistance of lacquers to perspiration.

Subcommittee XXIX on Painting of Metals (A. J. Eickhoff, chairman) is working on a method for the preparation of aluminum surfaces for painting, on a method of classifying ferrous surfaces for painting, and on a method for the preparation of magnesium surfaces for painting.

This report has been submitted to letter ballot of the committee, which consists of 352 voting members; 173 members returned their ballot, of whom 159 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

W. T. PEARCE,
Chairman.

W. A. GLOGER,
Secretary.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee D-1 presented to the Society through the Administrative Committee on Standards the Tentative Method of Test for Non-Volatile Matter of Lacquer Solvents and Diluents. The method was accepted by the Standards Committee on December 22, 1954, and it appears in the January, 1955, Compilation of ASTM Standards on Paint, Varnish, and Related Products, bearing the designation D 1353 – 54 T.

REPORT OF COMMITTEE D-2
ON
PETROLEUM PRODUCTS AND LUBRICANTS*

The following recommendations of the subordinate groups of Committee D-2 on Petroleum Products and Lubricants have been approved by Committee D-2, in accordance with the regulations of the Society, and are presented herewith.

PROPOSED METHODS TO BE PUBLISHED AS INFORMATION

Committee D-2 recommends that the following four proposed methods be published as information only, as appended to this report:[1]

Test for Filterability of Jet Fuel.

Test for Mercaptan Sulfur in Jet Fuels (Potentiometric Titration Method).

Test for Individual Hydrocarbons in a C_4 Fraction by Infrared Spectrophotometry.

Test for Emulsion Characteristics of Steam-Turbine Oils.

PROPOSED REVISIONS PUBLISHED AS INFORMATION

Committee D-2 recommends the following revisions of three tentative methods for publication as information only as appended to this report or as indicated below:

D 270 - 53 T,[2] Sampling Petroleum and Petroleum Products. The following revisions are under consideration by the committee and comments are solicited:

Section 6(d).—Change to read as follows:

"(*d*) *Package Lots* (*Cans, Drums, Barrels or Boxes*).—Samples shall be taken from a sufficient number of the individual packages which may be used to prepare a composite sample and which will be representative of the entire lot or shipment. The individual packages to be sampled shall be selected at random. The number of such random packages will depend upon several practical considerations such as:

(*1*) The tightness of the product specifications.

(*2*) The source and type of the material, and whether or not more than one production batch may be represented in the lot.

(*3*) Previous experience with similar shipments, particularly with respect to the uniformity of quality from package to package.

In most cases, the number specified in Table III will be satisfactory. During filling operations the first several packages usually are the most critical. Separate spot samples of these packages may be required in addition to the composite sample of the entire lot.

Table III.—Change to read as shown in the accompanying Table I.

Section 7.—Reletter as Paragraph (*a*) and add Paragraphs (*b*) and (*c*) as follows:

"(*b*) When sampling volatile products, the sampling apparatus shall be filled and allowed to drain before drawing the sample. If the sample is to be transferred to another container, this container shall also be rinsed with some of the volatile product and then drained. When the actual sample is emptied into this container, the sampling apparatus should be up-ended into the opening of the sample container and remain in this position until the contents have been transferred so that no unsaturated air will be entrained in the transfer of the sample."

"(*c*) When sampling other than volatile liquid products (2 lb RVP or less), the sampling apparatus shall be filled and allowed to drain before drawing the actual sample. If the actual sample is to be transferred to another container, the sample container shall be rinsed with some of the product to be sampled and drained before it is filled with the actual sample."

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13–18, 1954.

[1] These proposed methods appear in the November, 1954, Compilation of ASTM Standards on Petroleum Products and Lubricants.

[2] 1953 Supplement to Book of ASTM Standards, Part 5.

TABLE I.—MINIMUM NUMBER OF PACKAGES TO BE SELECTED FOR SAMPLING.

Total No. of Packages in Lot	No. of Packages to be Sampled	Total No. of Packages in Lot	No. of Packages to be Sampled	Total No. of Packages in Lot	No. of Packages to be Sampled
1 to 4	all	513 to 729	9	2745 to 3375	15
5 to 64	4	730 to 1000	10	3376 to 4096	16
65 to 125	5	1001 to 1331	11	4097 to 4913	17
126 to 216	6	1332 to 1728	12	4914 to 5832	18
217 to 343	7	1729 to 2197	13	5833 to 6859	19
344 to 512	8	2198 to 2744	14	6860 or over	20

D 1086 – 52 T,[3] Measuring Temperature of Petroleum and Petroleum Products, proposed revisions as appended hereto.[4]

D 1160 – 52 T,[3] Reduced Pressure Distillation of Petroleum Products, information concerning this method as appended hereto.[5]

NEW TENTATIVES

Committee D-2 recommends that the following seven methods of test be accepted for publication as tentative, as appended hereto[6] or as otherwise indicated:

Tentative Methods of Test for:

Tensile Strength of Paraffin Wax, revision as appended hereto[7] of method published as Appendix VII to the 1952 Report of Committee D-2.

Needle Penetration of Petroleum Waxes.

Smoke Point of Jet Fuel.

Mercaptan Sulfur in Jet Fuel (Amperometric Method).

Hydrocarbon Types in Liquid Petroleum Products by Fluorescent-Indicator Adsorption (FIA) Method.

Sodium in Residual Fuels by Flame Photometer.

Chlorine in Lubricating Oils (Sodium Alcoholate Volumetric Method), as published as information in 1953, in Appendix II to the 1953 Report of Committee D-2.[8]

REVISION OF TENTATIVES

Committee D-2 recommends the revision of the following six tentatives as indicated:

D 130 – 50 T,[3] Free and Corrosive Sulfur in Petroleum Products (Copper Strip Test), revised as appended hereto.[7]

D 381 – 52 T,[3] Existent Gum in Fuels by Jet Evaporation, revise as follows:

Note 1.—Revise to read:

"NOTE 1.—If the motor gasoline contains dissolved non-volatile additives, such material may be obtained as a residue along with the gum. Such residues may be extracted with normal pentane as described in the Appendix to determine the 'Solvent Washed' gum residue."

Section 8(d).—Change the last four sentences to read as follows: "Maintain the temperatures and rate of flow, and allow the fuel to evaporate for 30 min. Samples tested simultaneously should have equal evaporation characteristics."

Section 8(e).—Revise as follows:

"(*e*) At the end of the heating period, remove the beakers from the bath and visually examine the residues. Oily, greasy, or waxy appearance generally denotes the presence of additive material. Such residues are subject to supplementary processing for obtaining solvent washed gum residue as described in the Appendix. Place the beakers in the cooling vessel in the vicinity of the balance for at least 2 hr. Weigh the beakers (Note 3) in the same manner as in Paragraph (*c*), repeating the weighings until consecutive weights agree within 0.1 mg. If a single-pan type balance is used, correct the weights for any change in weight of the tare (blank) beaker.

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[3] 1952 Book of ASTM Standards, Part 5.

[4] See p. 411.

[5] See p. 416.

[6] The new tentatives were accepted by the Society and appear in the 1954 Supplement to Book of ASTM Standards, Part 5.

[7] The revised method was accepted by the Society and appears in the 1954 Supplement to Book of ASTM Standards, Part 5.

[8] *Proceedings*, Am. Soc. Testing Mats., Vol. 53, p. 369 (1953).

Note 3.—Add a new Note 3 to read as follows:

"NOTE 3.—The beakers containing additive material need not be weighed before processing unless the weight of the additive material is desired."

Appendix.—Add as an Appendix a procedure for obtaining gum in gasoline containing nonvolatile residue, as appended hereto.[7]

D 974 - 53 T,[2] Neutralization Value (Acid and Base Numbers) by Color Indicator Titration, revise as follows:

Note 6.—Add a new Note 6 following Note 5 to read as follows, renumbering subsequent notes and references thereto in the text accordingly:

"NOTE 6.—When samples are visibly free from sediment, the heating procedure described in Paragraph (*b*) may be omitted."

D 1016 - 52 T,[2] Determination of Purity from Freezing Points, revise as follows:

Section 12.—Add the following new section on *n*-octane, and renumber the subsequent sections accordingly:

"12. *n-Octane.*—(*a*) The freezing point is determined from freezing curves, with the cage stirrer, with a cooling bath of carbon dioxide refrigerant at a cooling rate of 0.3 to 0.8 C per min for the liquid near the freezing point, and with crystallization induced immediately below the freezing point by means of a cold rod.

(*b*) Obtain a sample of 50 ml (measured at room temperature) directly from its original container by means of a pipete or by pouring into a graduated cylinder.

(*c*) For *n*-octane, the freezing point for zero impurity, in air at 1 atmosphere, is:

$$t_1 = -56.795 \pm 0.010 \text{ C}$$

and the cryoscopic constants are:

A = 0.05329 mole fraction per degree,

B = 0.0031 mole fraction per degree.

(*d*) The cryoscopic constants given in Paragraph (*c*) are applicable to samples of *n*-octane having a purity of about 95 mole per cent or better, with the usual impurities and with no impurity present in an amount which exceeds the composition of its eutectic with the major component.

(*e*) The estimated uncertainty in the calculated value of the purity is as follows:

Calculated Purity, mole per cent	Uncertainty, plus or minus, mole per cent
Over 99.5	0.05
99.0 to 99.5	0.06
98 to 99	0.07
97 to 98	0.08
96 to 97	0.10
95 to 96	0.12"

Section 5.—Change the reference to Section "23" to read "24."

D 1086 - 52 T,[3] Measuring the Temperature of Petroleum and Petroleum Products, revise as follows:

Section 4(e).—In the first sentence change "thermometer well" to read "installed in a standard metal separable well or socket in the tank."

Section 4(f).—In the first sentence change "thermometer well" to read "installed in a standard metal separable well or socket in the tank."

Section 4(g).—In the first sentence change "thermometer well" to read "installed in a standard metal separable well or socket in the tank."

In the second sentence change "2.5" to read "sensitive portion not more than 6 in. long."

Section 7(a).—Change second sentence to read as follows:

"Therefore, such measurements are normally taken with thermometers in appropriate wells or separable sockets suitably located."

D 1091 - 50 T,[2] Phosphorus in Lubricating Oils, Lubricating Oil Additives, and Their Concentrates, revise as follows:

New Section.—Add a new Section 23, to read as follows:

"23. *Precision.*—The following data should be used for judging the acceptability of results (95 per cent probability):

"(*a*) Duplicate results by the same operator should be considered suspect if they differ by more than the amounts corresponding to the phosphorus contents on the accompanying Figs. 1 and 2, as follows:

REPEATABILITY

Photometric	*Gravimetric*
See Fig. 1	See Fig. 2

"(*b*) The results submitted by each of two laboratories should be considered suspect if they differ by more than the amounts corresponding to the phosphorus contents on the accompanying Figs. 3 and 4, as follows:

REPRODUCIBILITY

Photometric	*Gravimetric*
See Fig. 3	See Fig. 4"

Appendix.—Delete the Appendix.

REVISION OF STANDARD AND REVERSION TO TENTATIVE

Committee D-2 recommends that the Standard Method of Test for Distillation of Crude Petroleum (D 285 – 52) be reverted to tentative and extensively revised as appended hereto.[7]

ADOPTION OF TENTATIVES AS STANDARDS

Committee D-2 has reviewed the following eight tentatives which have stood one or more years without revision, and which represent best present-day practices, and recommends that they be approved for reference to letter ballot of the Society for adoption as standard:

Tentative Methods of Test for:

D 665 – 53 T,[2] Rust-Preventing Characteristics of Steam-Turbine Oil in the Presence of Water,
D 943 – 53 T,[2] Oxidation Characteristics of Inhibited Steam-Turbine Oils,
D 1095 – 50 T,[3] Analysis of 60 Octane Number *Iso*octane-Normal Heptane ASTM Knock Test Reference Fuel Blends by Infrared Spectrophotometry,
D 1096 – 50 T,[3] 1-3, Butadiene in C_4 Hydrocarbon Mixtures by Ultraviolet Spectrophotometry,
D 1157 – 51 T,[3] Total Inhibitor Content (*p*-Tertiary-Butylcatechol) of Butadiene, revised as appended hereto,[7]
D 1215 – 52 T,[3] Definition and Specifications for Farm Tractor Fuels,
D 1217 – 52 T,[3] Density and Specific Gravity of Liquids by Bingham Pycnometer,
D 1298 – 53 T,[2] Specific Gravity of Petroleum and Its Products (Hydrometer Method). (This method and Method D 287 – 53 T are intended to replace Standard Method D 287 – 52).

REVISION OF STANDARDS, IMMEDIATE ADOPTION

Committee D-2 recommends the immediate adoption of revisions of six standards as indicated below, and requests the necessary nine-tenths affirmative vote at the Annual Meeting so that these revisions may be referred to Society letter ballot:

D 86 – 53,[2] Distillation of Gasoline, Naphtha, Kerosine, and Similar Petroleum Products, revise as follows:

Section 2(a).—In the table change the present values corresponding to the last item Thickness of Vapor Tube Wall, under Permissible Variations to "±0.015 cm" and "±0.006 in.", respectively.

Section 2(c).—Delete and substitute wording as follows:

"(*c*) *Shield.*—Two types of shields can be used, as follows:

"*Type 1 Shield.*—A shield (Fig. 2) 19 in. high, 11 in. long and 8 in. wide, made of sheet metal approximately No. 22 gage, with a door on one narrow side, two openings 1 in. in diameter equally spaced in each of the two narrow sides, and with a slot cut in one side for the vapor tube. The centers of these four openings shall be 8½ in. below the top of the shield. There shall be three ½-in. holes in each of the four sides with their centers 1 in. above the base of the shield."

"*Type 2 Shield.*—A shield 17½ in. high, 8 in. long and 8 in. wide, made of sheet metal of approximately No. 22 gage, with window on front side. Open bottom of shield spaced approximately 2 in. from base of unit. Rear of shield to have eliptical hole for vapor tube. A flask adjusting knob located on the front of the shield for adjusting the flask support. Also heat adjusting indicating dial to provide stepless heat control when electric heater is used. All mechanism built into bottom portion of shield."

Section 2(d).—Delete, and substitute wording as follows:

"(*d*) *Flask Support and Ceramic or Asbestos Boards.*—A ring support of the ordinary laboratory type, 4 in. or larger in diameter, supported on a stand inside the shield, or a flask support platform that is adjustable from the outside of the shield may be used. Two ceramic or hard asbestos boards, the first having a hole 1¼-in.[3] in diameter in the center, and the thickness of the board at the 1¼-in. diameter open-

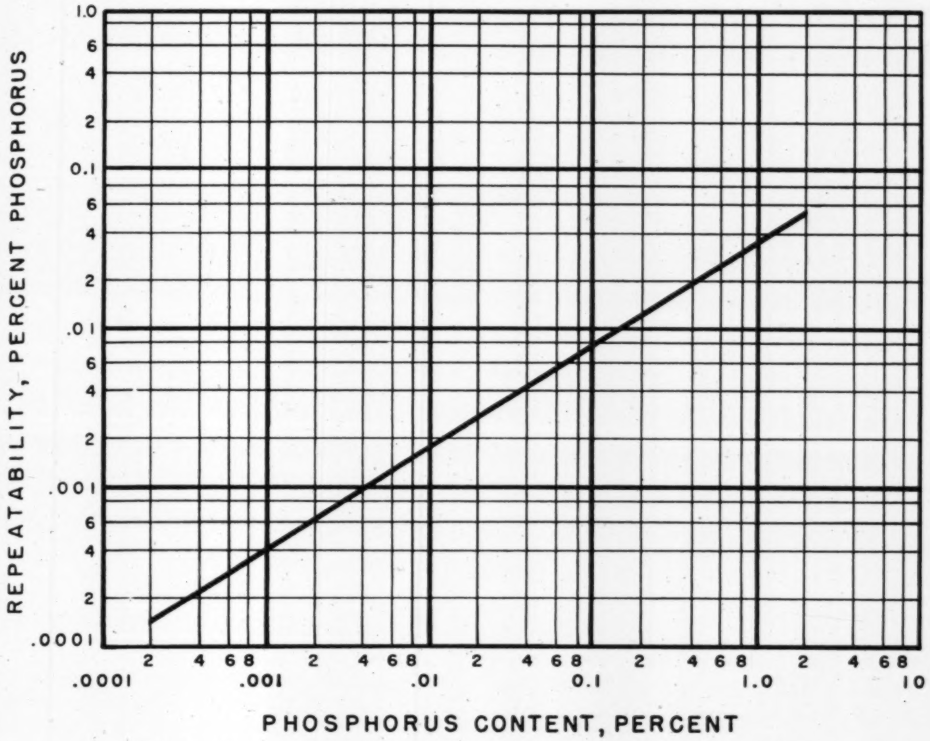

Fig. 1.—Repeatability of Method D 1091 by Photometric Procedure.

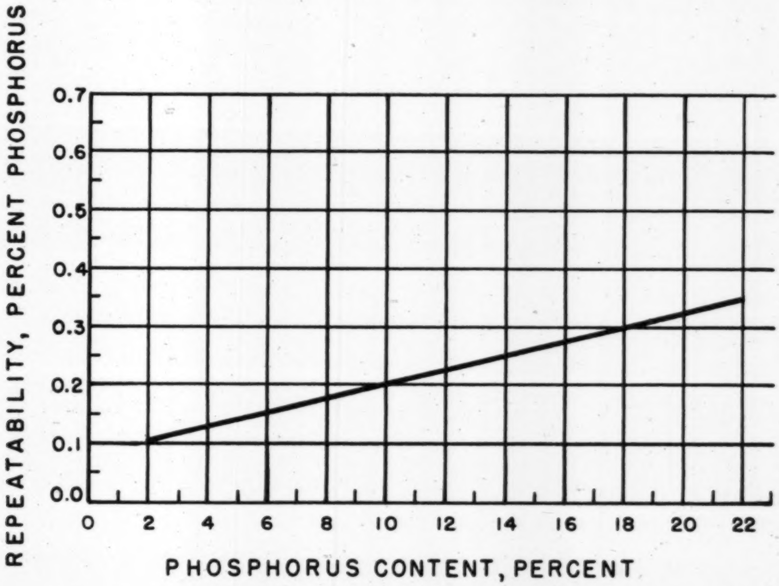

Fig. 2.—Repeatability of Method D 1091 by Gravimetric Procedure.

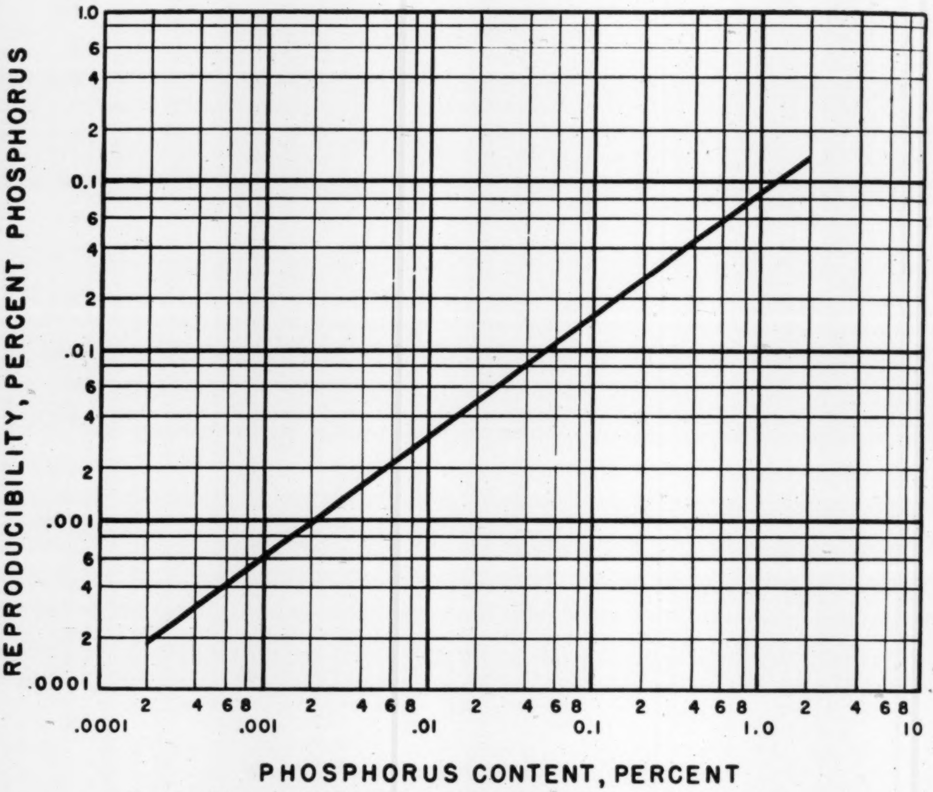

FIG. 3.—Reproducibility of Method D 1091 by Photometric Procedure.

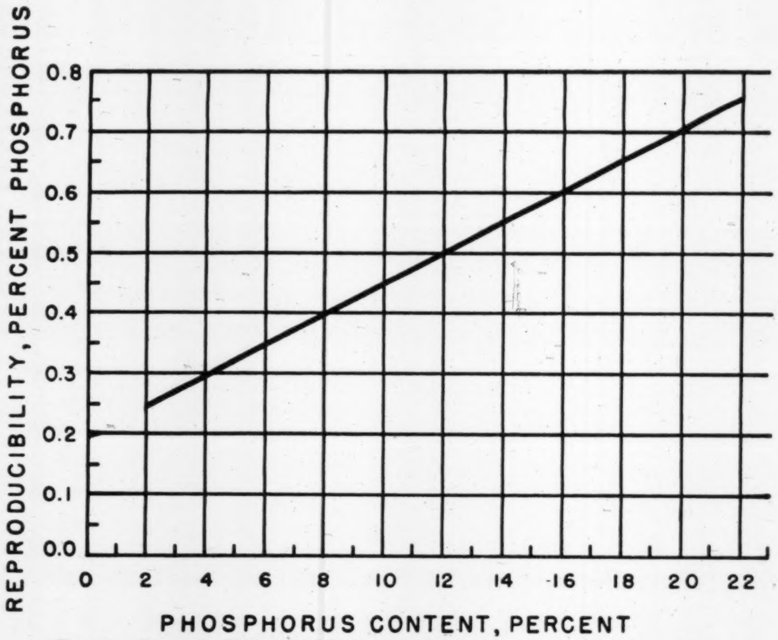

FIG. 4.—Reproducibility of Method D 1091 by Gravimetric Procedure.

ing shall be ⅛ to ¼ in.; the second board to fit tightly inside the shield with an opening 3 to 4 in. in diameter, concentric with the flask support. These shall be arranged as follows: The second board shall be placed on the support, and the first or smaller board on top so it may be moved in accordance with the directions for placing the distillation flask. Direct heat shall be applied to the flask only through the 1¼-in. diameter opening in the first board."

Section 2(f).—Delete, and substitute wording as follows:

"(*f*) *Electric Heater*.—An electric heater may be used instead of a gas burner and shall be capable of bringing over the first drop within the time specified in Section 4(*a*) when started cold, and of continuing the distillation at a uniform rate. (A heater unit of low-heat capacity, adjustable from 0 to 750 w, has been found satisfactory). The electric heater shall be fitted with a ceramic or hard asbestos board top having a hole 1¼ in.[3] in diameter in the center, and the thickness of the board at the 1¼-in. diameter opening shall be ⅛ to ¼ in. When an electric heater is employed, the portion of the shield above the board shall be the same as with the gas burner, but the part below the board may be omitted."

Footnote 3.—Revise this footnote by substituting the wording "... hole in the asbestos or ceramic board ..." for the wording "... hole in the asbestos board ..."

D 158 – 53,[2] Distillation of Gas Oil and Similar Distillate Fuel Oils, revise as follows:

Section 2(a).—Change the present permissible variations as given above under Section 2 (*a*) of Method D 86.

Section 2(c).—Change the requirements for the shields as given above under Section 2(*c*) of Method D 86, except in place of the reference to Fig. 2 add Footnote 3.

Section 2(d).—Change the requirements for the flask support and ceramic or asbestos boards as given above under Section 2(*d*) of Method D 86, except to require that the hole in the asbestos board be 2¾ in. in diameter, and delete the footnote.

Section 2(f).—Change the requirements for the electric heater as given above under Section 2(*f*) of Method D 86, except require that the hole in the asbestos board be of 2¾ in. in diameter, and delete the footnote.

D 216 – 53,[2] Distillation of Natural Gasoline, revise as follows:

Section 2(a).—Change the present permissible variations as given above under Section 2(*a*) of Method D 86.

Section 2(c).—Change the requirements for the shield as given above under Section 2(*c*) of Method D 86.

Section 2(d).—Change the requirements for the flask support and ceramic or asbestos boards as given above under Section 2(*d*) of Method D 86.

Section 2(f).—Change the requirements for the electric heater as given above under Section 2(*f*) of Method D 86, except to refer to Section 5(*a*) for the time specified.

D 287 – 52,[3] Gravity of Petroleum and Its Products by Hydrometer, replace this method by adoption as standard of the Tentative Method D 287 – 53 T, Test for API Gravity of Petroleum and Its Products (Hydrometer Method).[2]

D 664 – 52,[3] Neutralization Value (Acid and Base Numbers) by Potentiometric Titration.

Note 7.—Add a new Note 7 following Note 6, renumbering subsequent notes accordingly, to read as follows:

"NOTE 7.—When samples are visibly free from sediment, the heating procedures described in Paragraph 8(*b*) may be omitted."

D 939 – 52,[3] Saponification Number of Petroleum Products by Potentiometric Titration, this method has been completely revised as appended hereto.[7] These revisions are mostly editorial in nature

TENTATIVES CONTINUED WITHOUT REVISION

Committee D-2 has reviewed the following sixteen tentatives which have stood for two years without revision, and, for good and sufficient reasons, discussed within its subordinate groups, recommends that they be continued as tentatives without revision:

D 94 – 52 T, Saponification Number of Petroleum Products by Color-Indication Titration,
D 96 – 52 T, Water and Sediment by Means of Centrifuge,
D 447 – 52 T, Distillation of Plant Spray Oils,

D 483 - 52 T, Unsulfonated Residue of Petroleum Plant Spray Oils,
D 524 - 52 T, Carbon Residue of Petroleum Products (Ramsbottom Coking Method),
D 613 - 48 T, Ignition Quality of Diesel Fuels by the Cetane Method,
D 614 - 49 T, Knock Characteristics of Aviation Fuels by the Aviation Method,
D 808 - 52 T, Chlorine in Lubricating Oils and Greases by the Bomb Method,
D 893 - 52 T, Normal Pentane and Benzene Insolubles in Used Lubricating Oils,
D 909 - 49 T, Knock Characteristics of Aviation Fuels by the Supercharge Method,
D 1085 - 52 T, Gaging Petroleum and Petroleum Products,
D 1158 - 52 T, Bromine Number of Petroleum Distillates (Color-Indicator Method),
D 1159 - 52 T, Bromine Number of Petroleum Distillates (Electrometric Method),
D 1160 - 52 T, Reduced Pressure Distillation of Petroleum Products,
D 1218 - 52 T, Refractive Index and Refractive Dispersion of Hydrocarbon Liquids, and
D 1219 - 52 T, Mercaptan Sulfur in Jet Fuels (Color-Indicator Method).

AMERICAN STANDARDS

Committee D-2 recommends the following for action by ASA Sectional Committee Z11 on Petroleum Products and Lubricants:

Approval as American Standard:

Test for Specific Gravity of Petroleum and Its Products (Hydrometer Method) (D 1298 - 53 T), if adopted as ASTM Standard.

Reapproval of Revised American Standards:

Test for Gravity of Petroleum and Its Products by Hydrometer (D 287; Z11.31—1952), as revised in this report.
Test for Distillation of Gasoline, Naphtha, Kerosine, and Similar Petroleum Products (D 86; Z11.10—1953), as revised in this report.
Test for Distillation of Gas Oil and Similar Distillate Fuel Oils (D 158; Z11.26—1953), as revised in this report.
Test for Distillation of Natural Gasoline (D 216; Z11.11—1953), as revised in this report.
Test for Neutralization Value (Acid and Base Numbers) by Potentiometric Titration (D 664; Z11.59—1952), as revised in this report.
Test for Saponification Number of Petroleum Products by Potentiometric Titration (D 939; Z11.67—1952), as revised in this report.
Test for Distillation of Crude Petroleum (D 285; Z11.32—1952), as revised in this report.

The recommendations appearing in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[9]

This report has been submitted to letter ballot of the committee, which consists of 118 voting members; 75 members returned their ballots, of whom 61 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

O. L. MAAG,
Chairman.

W. T. GUNN,
Secretary.

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[9] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee D-2 presented to the Society through the Administrative Committee on Standards a recommendation for the revision of the Tentative Specifications for Gasoline (D 439 - 53 T). This recommendation was accepted by the Standards Committee on September 28, 1954, and the revised specifications appear in the 1954 Supplement to Book of ASTM Standards, Part 5, and in the November, 1954, Compilation of ASTM Standards on Petroleum Products and Lubricants.

APPENDIX I

PROPOSED REVISION OF TENTATIVE METHOD OF MEASURING TEMPERATURE OF PETROLEUM AND PETROLEUM PRODUCTS (D 1086 - 52 T)

EDITORIAL NOTE

The following changes in Method D 1086 are under consideration by Committee D-2 on Petroleum Products and Lubricants, and are published here as information only.

Section 4 (*h*).—Revise to read as follows:

(*h*) *Electrical Resistance Thermometers.*—Electrical resistance thermometers may be used for the determination of either **spot** or **average** temperatures, provided that the installation conforms with the minimum specifications for the design, installation and accuracy of such devices as described in the Appendix.

Appendix.—Add the following information on electrical resistance thermometers as an Appendix to the method:

APPENDIX

ELECTRICAL RESISTANCE THERMOMETERS

Basic Principle

A1. The electrical resistance thermometer operates on the basic principle that metals change their electrical resistance with changes in temperature. Since the temperature coefficients of resistance of certain metals are uniform, they may readily be used to measure temperature.

Description

A2. A resistance thermometer consists of one or more wire resistors or bulbs and a meter assembly for the indication of temperature. Either **spot** or **averaging** resistance bulbs may be used, depending upon the type of temperature desired. The meter assembly consists of a resistance network based upon the Wheatstone bridge principle, a voltage supply, and a galvanometer calibrated in degrees of Fahrenheit temperature. A typical circuit is shown in Fig. A-1. A ratio-type meter, or its equivalent, may be used in the circuit. The ratio-type meter is a modification of the conventional Wheatstone bridge network and is designed to eliminate errors caused by variations in voltage. If a standard bridge circuit is used, means must be provided for control of the voltage. The galvanometer or meter scale should be graduated in single Fahrenheit degrees over the range required and it shall be calibrated for the type of wire used in the resistance units. The meter may be located at the top of the tank, at ground level, or at any convenient location for remote reading.

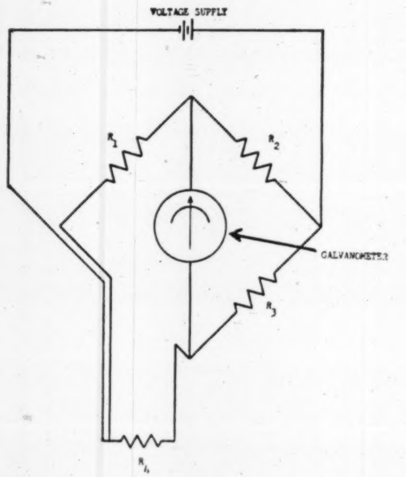

VOLTAGE SUPPLY
R1
R2
GALVANOMETER
R3
R4

FIG. A-1.—Basic Wiring Diagram of Resistance Thermometer Circuit.

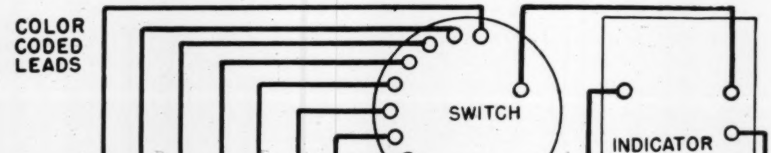

COLOR CODED LEADS
SWITCH
INDICATOR
SWITCH
40'
32'
26'
20'
14'
10'
7'
5'
3'
50 FT. TANK
BOTTOM OF TANK

FIG. A-2.—Schematic Wiring Diagram of Typical Averaging Resistance Bulb.

Resistance Bulb for Spot *Temperatures*

A3. The spot type of resistance bulb consists of a wire resistance unit suitably housed and provided with leads. The housing shall be of both corrosion-resistant and non-sparking material with leads sealed against contamination of conductors or connections. The individual bulb shall be installed through the tank shell at the required level through conventional separable sockets. If a given tank is equipped with more than one resistor bulb in order that spot temperatures may be determined at different points in the tank, a multi-point selector switch shall be used to connect the desired resistor to the meter. Should one meter located at a central point be used to determine the temperature from single resistor bulbs in a number of different tanks, a selector switch shall be used to connect the desired resistor to the meter.

Portable Unit for Spot *Temperature Determination*

A4. A portable unit can be assembled by housing the meter assembly and batteries in a convenient carrying case. A spot type of resistance bulb is attached to a flexible three-conductor cable of sufficient length to lower it through the gaging hatch to any desired level.

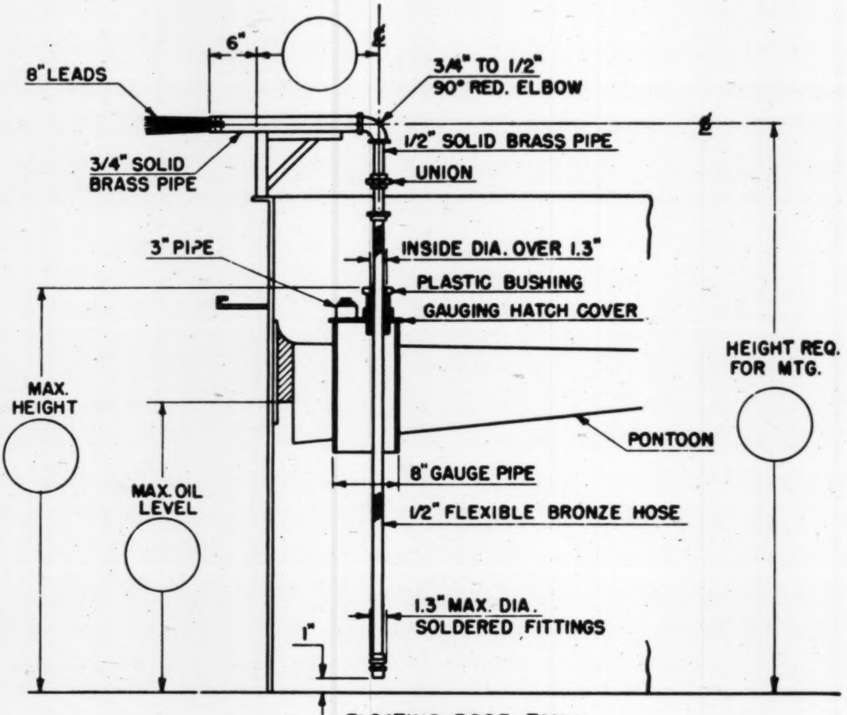
Resistance Bulb for Average *Temperatures*

A5. (*a*) In the averaging type, the resistance bulb (Fig. A-2) consists of an assembly of insulated resistance units of various lengths, each being of equal resistance, evenly distributed over its entire length. The units are assembled in cable form and inserted in a flexible hose or thin-walled pipe to form the "bulb." The flexible hose or pipe shall be made of corrosion-resistant and spark-proof material. The insulation used to cover the individual resistance units must be capable of withstanding the maximum temperature to which it may be subjected. The number of individual resistance units which make up the "bulb" will depend upon the height of the tank, but in all cases the entire working range of the tank shall be covered. In tanks where a closing gage of 3 ft or less is sometimes necessary, the bulb shall be equipped with a "spot" reading resistor at the 2-ft. level. The non-merchantable oil level shall be maintained at least 1 ft below the "spot" reading resistor.

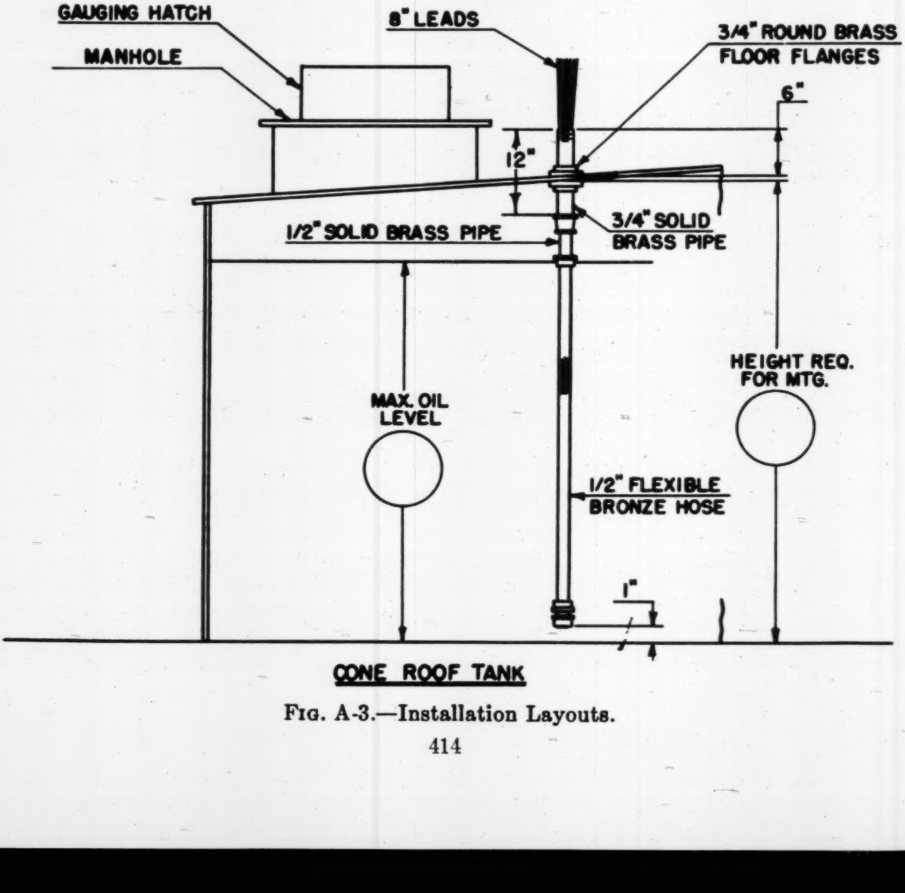
(*b*) *Installation on Conventional Tanks.*—The flexible hose or the pipe containing the bundle of resistors shall be suspended vertically in the tank by passing it through a flange in the tank roof located not less than 18 in. from the shell of the tank (see Fig. A-3).

(*c*) *Installation on Floating Roof Tanks.*—For a floating roof tank installation, the flexible hose shall be suspended vertically from an angle bracket located on top of the tank shell and shall pass through the gaging hatch or other opening on the floating roof at least 18 in. from the tank shell (see Fig. A-3). The angle bracket should be installed high enough to prevent damage by the floating roof in case of overfilling.

(*d*) *Selector Switch.*—A multipoint selector switch shall be used to permit the separate connection to the meter of each resistor contained in the averaging bulb. The switch dial shall be marked to indicate the range of oil level served by the respective point for each resistor. For installations in floating roof tanks, the switch dial marking shall be corrected for the depth of oil in the roof gaging pipe, because the oil contained in the pipe may be several degrees different from the temperature of the main body of oil in the tank. In other words, the bundle or bulb is not to be energized within the roof level. In operating the assembly, it is only necessary to turn the selector switch to the setting which


6"
℄
8" LEADS
3/4" TO 1/2"
90° RED. ELBOW
℄
1/2" SOLID BRASS PIPE
3/4" SOLID
BRASS PIPE
UNION
3" PIPE
INSIDE DIA. OVER 1.3"
PLASTIC BUSHING
GAUGING HATCH COVER
HEIGHT REQ.
FOR MTG.
MAX.
HEIGHT
PONTOON
MAX. OIL
LEVEL
8" GAUGE PIPE
1/2" FLEXIBLE BRONZE HOSE
1.3" MAX. DIA.
SOLDERED FITTINGS
1"

FLOATING ROOF TANK


GAUGING HATCH
MANHOLE
8" LEADS
3/4" ROUND BRASS
FLOOR FLANGES
6"
12"
1/2" SOLID BRASS PIPE
3/4" SOLID
BRASS PIPE
HEIGHT REQ.
FOR MTG.
MAX. OIL
LEVEL
1/2" FLEXIBLE
BRONZE HOSE
1"

CONE ROOF TANK

FIG. A-3.—Installation Layouts.

corresponds to the longest completely submerged resistor. When the current is applied, the average temperature is indicated immediately on the meter scale.

Certification for Accuracy

A6. Electrical-resistance thermometers of either the **spot** or **averaging** type shall be accurate to ±1.0 F. Such installations shall be checked for accuracy immediately after the installation is completed, at least at annual intervals thereafter, and, in addition, at any time that the reading appears to be inaccurate for any reason. The installation shall be checked by comparing the reading shown on the meter with that shown by a cup or flushing case thermometer of known accuracy. In checking the **spot** type, the cup case shall be lowered to the same point as the spot bulb and the same distance from the tank shell. For the **averaging** type, the cup case shall be lowered through the roof the same distance from the shell and a sufficient number of temperature readings at various levels shall be carefully obtained, the average of which shall be used to compare with the temperature shown on the meter of the averaging thermometer at the same depth of oil in the tank. Should the electrical resistance type fail to agree within 1 F. of the average of the cup case determinations, the meter assembly should be checked by comparing the meter reading with that shown when a standard resistor is substituted for the resistor bulb connected to the meter. A slow response on the meter indicator denotes low operating voltage. An "off scale" reading on the upper end of the scale denotes an open circuit in a resistance unit or at the terminals or leads. An "off scale" reading on the lower end of the scale usually denotes a short circuit in a resistance unit or in the leads.

APPENDIX II

INFORMATION CONCERNING THE TENTATIVE METHOD OF TEST FOR REDUCED PRESSURE DISTILLATION OF PETROLEUM PRODUCTS (D 1160 - 52 T)

Refer to Section 3 on Apparatus and Section A1 on Distillation Apparatus Assembly of the Tentative Method of Test for Reduced Pressure Distillation of Petroleum Products (ASTM Designation: D 1160 - 52 T).

Section *E* of Research Division VIII of Committee D-2 has conducted cooperative studies of the Tentative Method for Reduced Pressure Distillation in an effort to improve the precision of the test by revision of the apparatus. One proposed modification included the replacement of the asbestos-covered column and the condensers with a vacuum-jacketed single unit 1 as shown in Fig. 1.[1] Actually the vacuum-jacketed column was extended to include part of the neck of the present flask. A quartz-fiber heating mantle[2] for the flask was used in conjunction with the new column.

Although the apparatus modification did not result in any material improvement of the precision of the method, the equivalence of the data obtained in the cooperative studies indicated that the new arrangement might be used alternatively with the equipment specified in the Method D 1160 - 52 T. Since some cooperators feel that certain conveniences are obtained from the use of the vacuum-jacketed column and the flask heating mantle, pertinent information is supplied herewith to permit other laboratories to try the suggested design.

Distillation data on three samples were obtained at several pressure levels, by use of both the regular equipment and the vacuum-jacketed equipment. A tabulation of the precision of these data compared with the acceptability limits specified in Method D 1160 - 52 T is shown:

Repeatability.—Duplicate results by the same operator should not differ by more than the following amounts:

Pressure Range, mm of mercury, absolute	Using Standard Equipment	Using Modified Equipment	Limits from Method D 1160 - 52 T
1.........	17 F	6 F	10 F
10.........	7 F	8 F	8 F
50.........	10 F	8 F	10 F

Reproducibility.—The averages of duplicate results obtained in different laboratories should not differ by more than the following amounts:

Pressure Range, mm of mercury, absolute	Using Standard Equipment	Using Modified Equipment	Limits from Method D 1160 - 52 T
1.........	24 F	31 F	20 F
10.........	25 F	29 F	15 F
50.........	25 F	55 F	20 F

The noticeably poorer reproducibility obtained in this study was attributed to the fact that the slopes of the distillation curves of two of the samples were significantly greater than that of any sample previously studied.

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[1] The column assembly may be obtained from the Glass Engineering Laboratories (Attn: Mr. Robert Davis), 6309 S. Broadway, Los Angeles 3, Calif., by specifying the "C. F. Braun and Co. Vacuum-Jacketed Distillation Head for ASTM Method D 1160."

[2] The heating assembly may be obtained from the Glas-Col Apparatus Co. (Attn: Dr. G. H. Morey), 711 Hulman St., Terre Haute, Ind., by specifying "Special Quartz Heating Mantle, catalog No. SO-2-16-53-B, and Insulating Top, catalog No. SO-2-16-53-T"; both for 500-ml flask.

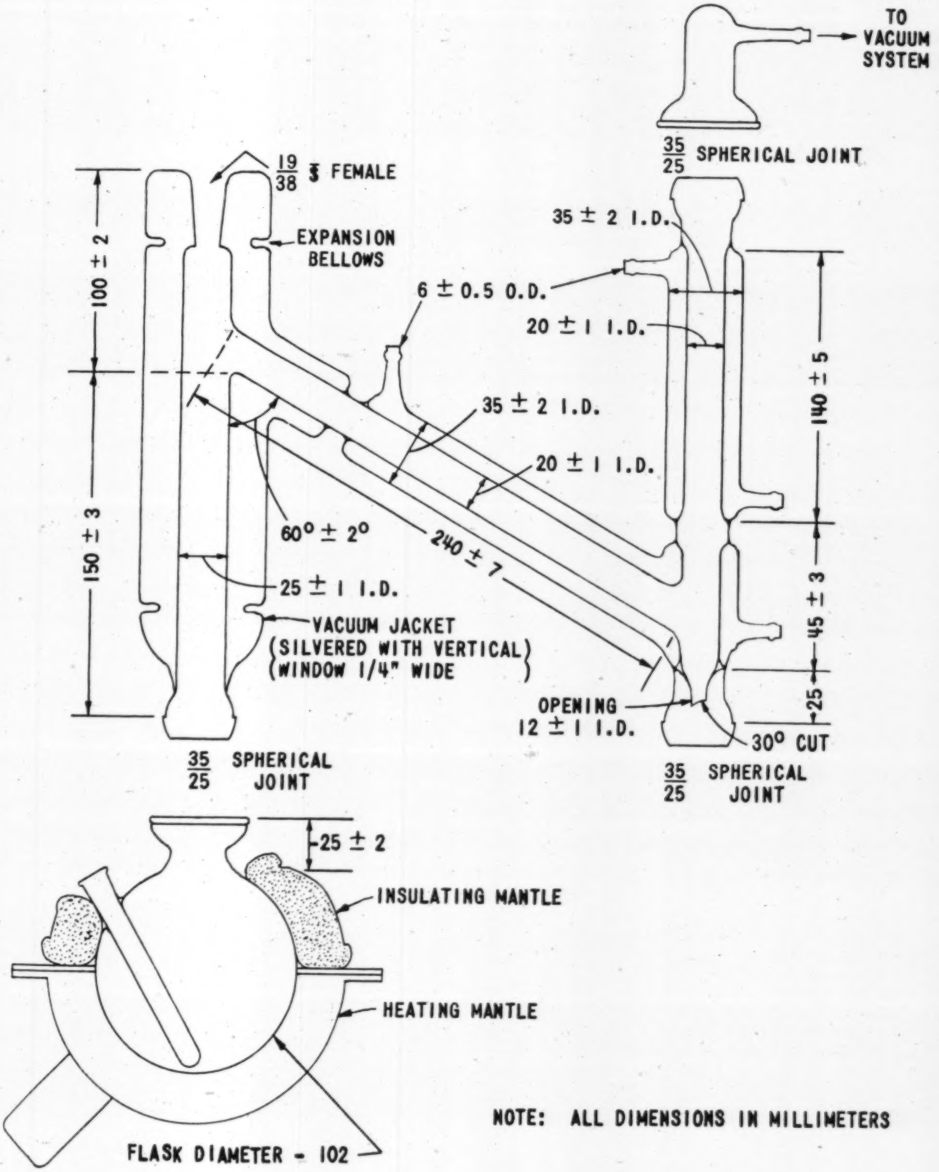
TO VACUUM SYSTEM
35/25 SPHERICAL JOINT
19/38 Ŝ FEMALE
EXPANSION BELLOWS
100 ± 2
150 ± 3
35 ± 2 I.D.
6 ± 0.5 O.D.
20 ± 1 I.D.
35 ± 2 I.D.
20 ± 1 I.D.
140 ± 5
60° ± 2°
240 ± 7
25 ± 1 I.D.
VACUUM JACKET
(SILVERED WITH VERTICAL WINDOW 1/4" WIDE)
OPENING 12 ± 1 I.D.
45 ± 3
25
30° CUT
35/25 SPHERICAL JOINT
35/25 SPHERICAL JOINT
25 ± 2
INSULATING MANTLE
HEATING MANTLE
FLASK DIAMETER - 102
NOTE: ALL DIMENSIONS IN MILLIMETERS

FIG. 1.—Vacuum-Jacketed Column Assembly and Heating Mantle.

REPORT OF COMMITTEE D-3
ON
GASEOUS FUELS*

Committee D-3 on Gaseous Fuels and its seven subcommittees held a joint meeting in Atlantic City, N. J., on June 30, 1953. Individual meetings of four of its subcommittees were held the previous day. Two additional subcommittee meetings were held in Washington, D. C., on February 1, 1954.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, L. T. Bissey.

Vice-Chairman, F. E. Vandaveer.

Secretary, K. R. Knapp.

Advisory Committee: S. W. Burdick, A. W. Gauger, G. C. Putnam, and E. F. Schmidt.

Recommendation Accepted by the Administrative Committee on Standards

Subsequent to the 1953 Annual Meeting, Committee D-3 presented to the Society through the Administrative Committee on Standards the proposed Tentative Method for Analysis of Carbureted Water Gas by the Mass Spectrometer, as prepared by Subcommittee VII. The method was accepted by the Standards Committee on November 9, 1953, and it appears in the 1953 Supplement to Book of ASTM Standards, Part 5, bearing the designation D 1302 - 53 T.

Adoption of Tentative as Standard

Committee D-3 recommends that the Tentative Method of Sampling Manufactured Gas (**D 1247 - 52 T**)[1] be approved for reference to letter ballot of the Society for adoption as standard.

This recommendation has been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[2]

Activities of Subcommittees

Subcommittee I on Collection of Gaseous Samples (F. E. Vandaveer, chairman).—The Tentative Method of Sampling Manufactured Gas (D 1247 - 52 T) was originally prepared by this subcommittee, and the recommendation for its adoption as standard was made by the subcommittee.

Subcommittee II on Measurement of Gaseous Samples (H. S. Bean, chairman).—Two meetings of this subcommittee were held during the year. Principal attention was devoted to the preparation of a procedure for calibration of the 0.1-cu ft wet test meter so that revisions of the Tentative Methods for Measurement of Gaseous Fuel Samples (D 1071 - 49 T) could be made to clarify some meter calibration details.[3] The subcommittee has approved the procedure prepared by a special task group.

Subcommittee III on Determination of Calorific Value of Gaseous Fuels (R. S. Jessup, chairman).—Material circulated to all subcommittee members on the reproducibility of results as covered in Section 20 of the Standard Method of Test for Calorific Value of Gaseous

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13–18, 1954.

[1] 1952 Book of ASTM Standards, Part 5.

[2] The letter ballot vote on this recommendation was favorable; the results of the vote are on record at ASTM Headquarters.

[3] See Editorial Note, p. 419.

Fuels by the Water Flow Calorimeter (D 900 - 48) was considered in detail at the June 29 meeting. Possibilities for making provisions of the method more definite and for specifying more rigid limits were reviewed. These included probable effects on reproducibility of factors such as temperature, barometric pressure, heating value of the gas, and relative humidity, as well as differentiating between reproducibility of the humidity control and humidity correction methods.

It was agreed that liaison would be maintained with the task group of Subcommittee II formed to prepare procedures for calibration of the 0.1-cu ft wet test meter.

Subcommittee V on Determination of Special Constituents of Gaseous Fuels (L. T. Bissey, chairman).—At the June 29 meeting, results of letter ballot on the referee method for sulfur determination were fully discussed. Some objections were recognized to apply to this method and it was decided not to recommend it for publication as tentative at this time.

A method for determination of organic and total sulfur is now in the hands of the members for letter ballot approval.

Also consideration has been given to the Lusby platinum spiral method for sulfur determination. An outline of the steps to be taken, prepared by one of the members, has been circulated to the subcommittee for review and comment.

Subcommittee VI on Determination of Water Vapor Content of Gaseous Fuels (S. W. Burdick, chairman).—Further experimental work was continued during the year on use of the Brickell method for determination of water vapor in gas.

Subcommittee VII on Complete Analysis of Chemical Composition of Gaseous Fuels (M. J. Stross, chairman).—The sad news of the sudden death of Martin Shepherd on September 17, 1953, came as a great shock to his many friends and associates. He had served as chairman of Subcommittee VII continuously since its organization and was personally responsible for many of its accomplishments. He was succeeded as chairman by M. J. Stross, long a member of this committee, and particularly qualified to direct its activities.

This subcommittee prepared the Tentative Method for Analysis of Carbureted Water Gas by the Mass Spectrometer (D 1302 - 53 T), mentioned earlier in the report as having been accepted during the year by the Administrative Committee on Standards.

This report has been submitted to letter ballot of the committee, which consists of 37 members; 24 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

A. W. Gauger,
Chairman.

K. R. Knapp,
Secretary.

Editorial Note

Subsequent to the Annual Meeting, Committee D-3 presented to the Society through the Administrative Committee on Standards the following recommendations:

Tentative Method for:

Determination of Total Sulfur in Fuel Gases (D 1072 - 54 T).

Revision of Tentative Methods for:

Measurement of Gaseous Fuel Samples (D 1071 - 49 T).

These recommendations were accepted by the Standards Committee on September 28, 1954, and the new and revised methods appear in the 1954 Supplement to Book of ASTM Standards, Part 5.

REPORT OF COMMITTEE D-4

ON

ROAD AND PAVING MATERIALS*

Committee D-4 on Road and Paving Materials held two meetings during the past year: in Atlantic City, N. J., on July 3, 1953, and in Washington, D. C., on February 5, 1954. At the February meeting, Committee D-4 observed its Fiftieth Anniversary. The original Committee H on Standard Tests for Road Materials, redesignated Committee D-4 on May 1, 1910, held its first meeting, for the purpose of organization, on February 8, 1904, and presented its first report to the Society at the Seventh Annual Meeting, at Atlantic City, June 19, 1904.

In the period since presentation of the last annual report, the committee has lost one of its active members by death. It is with sincere regret that the passing of Francis L. Mark on July 25, 1953, and the death on October 19, 1953, of Hugh W. Skidmore, a long-time member who only recently resigned from the committee, are recorded in this report.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, Charles W. Allen.

First Vice-Chairman, Kenneth B. Woods.

Second Vice-Chairman, Fred Hubbard.

Third Vice-Chairman, John O. Izatt.

Secretary, John M. Griffith.

Recommendations Accepted by the Administrative Committee on Standards

Subsequent to the 1953 Annual Meeting, Committee D-4 presented to the Society through the Administrative Committee on Standards the following recommendations:

Tentative Revisions of Standard:

Definitions of Terms Relating to Materials for Road and Pavements (D 8 - 52),

Method of Test for Distillation of Tars and Tar Products (D 20 - 52), and

Method of Test for Distillation of Cut-Back Asphaltic Products (D 402 - 49).

These recommendations were accepted by the Administrative Committee on Standards on September 9, 1953, and the tentative revisions appear in the 1953 Supplement to Book of ASTM Standards, Part 3.

The tentative revisions of definitions included the withdrawal of the standard definition for 'Slag" and the substitution of a definition for "Blast-Furnace Slag" corresponding to the definition in Standard Definitions of Terms Relating to Concrete and Concrete Aggregates (C 125 - 48); revisions of definitions for "Asphalt" and "Pitches" to state definitely that these materials are residua; and a modification of the tentative revision of the term "Tar" issued in June, 1949, which is incorrect and includes materials other than tar.

The tentative revisions of the distillation test methods remove statements relating to supplementary tests on distillation residues improperly incorporated in the distillation test procedures and otherwise improve the wording. Also more definite requirements for the glass-jacketed condenser used in Method D 402 have been provided.

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13-18, 1954.

REVISIONS OF TENTATIVES

Tentative Specifications for Hot-Mixed, Hot-Laid Asphaltic Concrete for Base and Surface Courses (**D 947 - 52 T**).[1]—Committee D-4 recommends the following revisions in these specifications:

Table I.—For Size No. 3, 2-in. Sieve, change "95 to 100" to "90 to 100."

This recommendation is in conformity with a recommendation for immediate revision of Standard Specifications for Standard Sizes of Coarse Aggregate for Highway Construction (D 448 - 49) subsequently presented in this report.

Table III.—Change bitumen requirements to read as follows:

Nominal Maximum Size of Aggregate					
2 in.	1½ in.	1 in.	¾ in.	½ in.	⅜ in.
Bitumen, per cent by Weight of Total Mixture					
3.5 to 7.5	4.0 to 8.0	4.0 to 8.5	4.5 to 9.0	5.0 to 9.5	5.5 to 10.0

Field experience in using some of the heavier aggregates, such as heavy limestone or traprock, has indicated that satisfactory percentages of bitumen may be lower than the minima presently required by these specifications.

Tentative Method of Test for Bitumen Content of Paving Mixtures by Centrifuge (**D 1097 - 50 T**).[1]—To provide for the determination of bitumen in mixtures containing aggregate of a larger maximum size, for the use of solvents other than benzene, and for the use of apparatus other than the Dulin Rotarex, Committee D-4 recomends the following revisions of this tentative method:

Section 1.—In the first sentence, change "½-in. sieve" to "1-in. sieve." In the Note, change the first two sentences to read:

> "Although 'bitumen' by definition is material soluble in carbon disulfide, benzene is recommended for use in this method for safety reasons, and it normally produces the same results within the precision of the method. Other solvents, such as carbon tetrachloride, trichlorethylene, etc., may be substituted for benzene or carbon disulfide in this method and similar results may be obtained, but the relationship of such results to those obtained with benzene or carbon disulfide cannot be predicted or assumed."

Also in the Note, make a separate paragraph of the last sentence.

Section 2(a).—In the first sentence, change "bowl as shown in Fig. 1" to "bowl approximating that shown in Fig. 1."

Section 4(a).—Change the last two sentences to read:

> "The precision of the method becomes less as the aggregate size increases, due to variations in samples. It may, however, be used on mixtures containing aggregate larger than 1 in. by using samples weighing at least 3000 g. They may be tested by extracting 1000 g. at a time."

Section 4(c).—Change the weight of sample for determination of water from "100 g." to "500 g."

TENTATIVE REVISION OF STANDARD

Standard Specifications for Crushed Stone, Crushed Slag, and Gravel for Water-Bound Macadam Base and Surface Courses of Pavements (**D 694 - 49**).[1]—To provide a requirement for soundness of aggregates used in water-bound macadam construction, Committee D-4 recommends publication of tentative revisions of this standard as follows:

New Section 5.—Add the following new Section 5, and renumber the present Section 5 and succeeding sections:

> "5. *Soundness.*—Coarse aggregate, when subjected to five cycles of the Soundness Test, shall

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[1] 1952 Book of ASTM Standards, Part 3.

have a weighted loss of not more than 20 per cent when sodium sulfate is used or 30 per cent when magnesium sulfate is used.

New Paragraph 7(d).—Add new Paragraph 7(*d*), and renumber the present Paragraph 7(*d*) as 7(*e*):

"(*d*) *Soundness.*—Tentative Method of Test for Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate (ASTM Designation: C 88 - 46 T)."

REVISIONS OF STANDARDS, IMMEDIATE ADOPTION

Standard Specifications for Standard Sizes of Coarse Aggregate for Highway Construction (**D 448 - 49**),[1]

Standard Specifications for Crushed Stone and Crushed Slag for Bituminous Macadam Base and Surface Courses of Pavements (**D 693 - 49**),[1] and

Standard Specifications for Crushed Stone, Crushed Slag, and Gravel for Water-Bound Macadam Base and Surface Courses of Pavements (**D 694 - 49**).[1]

Prompted by the consideration that the present requirement for Size No. 3 is illogical when comparison is made with other sizes of similar length and is impractical from the standpoint of production, Committee D-4 recommends the following revision of these three standard specifications for immediate adoption, and accordingly requests the necessary nine-tenths affirmative vote at the Annual Meeting in order that the recommendations may be referred to letter ballot of the Society:

Table I.—Change the requirement for amount finer than 2-in. sieve, per cent by weight, Size No. 3, from "95 to 100" to "90 to 100."

ADOPTION OF TENTATIVES AS STANDARD

Committee D-4 recommends that the following tentatives be approved for reference to letter ballot of the Society for adoption as standard:

Tentative Method of Test for Effect of Water on Cohesion of Compacted Bituminous Mixtures (**D 1075 - 49 T**),[1]

Tentative Specifications for Asphaltic Mixtures for Sheet Asphalt Pavements (**D 978 - 52 T**),[1]

Tentative Specifications for Fine Aggregate for Sheet Asphalt and Bituminous Concrete Pavements (**D 1073 - 51 T**),[1] and

Tentative Specifications for Crushed Stone, Crushed Slag, and Gravel for Bituminous Concrete Base and Surface Courses of Pavements (**D 692 - 51 T**),[1] revised as follows:

Table I.—Change the requirement for amount finer than 2-in. sieve, per cent by weight, Size No. 3, from "95 to 100" to "90 to 100."

Subject to approval of a similar recommendation by Committee D-8, Committee D-4 also recommends that Tentative Methods of Sampling Bituminous Materials (D 140 - 52 T) be approved for reference to letter ballot of the Society for adoption as standard.

Committee D-4 joins with Committee C-9 on Concrete and Concrete Aggregates in recommending that the Tentative Method of Test for Soft Particles in Coarse Aggregates (C 235 - 49 T)[1] be approved for reference to letter ballot of the Society for adoption as standard without change.

ADOPTION OF TENTATIVE REVISION AS STANDARD

Standard Methods of Testing Emulsified Asphalts (**D 244 - 49**).[1]—Subject to approval of a similar recommendation by Committee D-8, Committee D-4 recommends that the tentative revisions of this standard issued September 5, 1952,[1] be approved for reference to letter ballot of the Society for adoption as standard.

EDITORIAL REVISION

Standard Method of Test for Hot Extraction of Asphaltic Materials and Recovery of Bitumen by the Modified Abson Procedure (**D 762 - 49**).[1]—To clarify the illustration, Committee D-4 recommends that changes be made in

Fig. 2 to show the arrow pointing to the vertical portion of the distillation column rather than to its side arm, and to show diameters of the column and side arm as well as height of the column.

TENTATIVES CONTINUED WITHOUT REVISION

The subcommittees of Committee D-4 and the joint subcommittee of Committees D-4 and D-18 have reviewed existing tentative specifications and methods of test which have been published by the Society for two years or more without revision, and Committee D-4 recommends that the following be continued as tentative without revision:

Tentative Specifications for Asphalt Cement for Use in Pavement Construction (D 946 - 47 T).—These specifications should be retained as tentative pending the development of additional requirements and appropriate methods of testing to secure and control the properties of asphalt cement necessary to assure durability and uniformity.

Tentative Specifications for Preformed Expansion Joint Fillers for Concrete, Non-extruding and Resilient Types (D 544 - 52 T).—An extensive cooperative testing program on preformed expansion joint fillers is in progress, and the tentative specifications should be continued until a review of data indicates the desirability of further action on specification requirements.

Tentative Specifications for Concrete Joint Sealer, Hot-Poured Elastic Type (D 1190 - 52 T).—Further consideration is being given to requirements of this specification and it should accordingly be retained as tentative.

Tentative Specifications for Crushed Stone, Crushed Slag, and Gravel for Single Bituminous Surface Treatment (D 1139 - 52 T).—Additional specifications for aggregates suitable for other types of surface treatment are being considered and it is desirable to continue these tentative specifications until their relation to other specifications for surface treatment aggregates can be determined.

Tentative Specifications for Materials for Soil-Aggregate Subbase, Base, and Surface Courses (D 1241 - 52 T).—These tentative specifications are under the joint jurisdiction of Committee D-4 and Committee D-18 on Soils for Engineering Purposes. The joint subcommittee is studying requirements of these specifications with a view to their clarification and improvement.

Tentative Method of Test for Loss on Heating of Oil and Asphaltic Compounds (D 6 - 39 T).—This method does not have the reproducibility believed desirable for recommending adoption as standard, and efforts are being made to design testing equipment which will have satisfactory performance characteristics and control. The tentative method has been in extensive use for many years, notwithstanding its known deficiencies, and should be retained until an improved method can be established.

Tentative Method of Test for Moisture-Density Relations of Soils (D 698 - 42 T).—Committee D-18 on Soils for Engineering Purposes, which has joint jurisdiction with Committee D-4 on this tentative method, is considering a revision of the method.

Tentative Method of Testing Soil-Bituminous Mixtures (D 915 - 47 T).—Further study of this procedure is desirable in respect to correlation with construction control and service performance of highway soils. The method is in use by a number of highway construction agencies, and it is expected that a subcommittee of Committee D-18, which has joint jurisdiction for this tentative with Committee D-4, will assemble appropriate data on the applicability and utility of the tentative method under practical conditions.

Tentative Method of Test for Shear Strength of Flexible Road Surfaces, Subgrades, and Fills by the Burggraf Shear Apparatus (D 916 - 47 T).—Considerable information has been obtained by use of this apparatus, and it is expected that when the data are correlated with the service behavior of the soils a revision of the method may be indicated. Further research on the utility and application of this method of testing appears desirable.

Tentative Method of Test for Compressive Strength of Bituminous Mixtures (D 1074 - 52 T).—A subcommittee of Committee D-4 is conducting a study of this method which may lead to recommendations for revision; in the meantime the method should be continued.

Tentative Method of Test for Vacuum Distillation of Liquid and Semi-Solid Asphaltic Materials to Obtain a Residue of Specified Penetration (D 1189 - 52 T). —The committee desires to retain this method as tentative to permit the development of improvements based on use and experience.

Tentative Methods of Testing Concrete Joint Sealers (D 1191 - 52 T).—Further consideration is being given to these methods, and they should accordingly be continued as tentative.

Tentative Revision of Standard:

The committee desires to retain the tentative revision, issued in February, 1952, of the Standard Specifications for Sodium Chloride (D 632 - 43) for the possible development of criticism.

The recommendations appearing in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[2]

ACTIVITIES OF SUBCOMMITTEES

Subcommittee B-3 on Distillation Tests (J. W. Donegan, chairman) is conducting cooperative tests as a basis for developing statements on reproducibility for the standard distillation tests applied to asphaltic and tar road materials. The subcommittee is also cooperating closely with a group representing Committee D-2 in the preparation of a revised Method of Test for Water in Petroleum Products and Other Bituminous Materials.

Subcommittee B-5 on Softening Point Tests (I. E. Manning, chairman) is planning a thorough study of the Standard Method of Test D 36 - 26 for Softening Point with a view to improving the control of rate of heating and reproducibility of this method, and will make use of extensive data derived in several series of cooperative tests conducted in the last several years for a comparison of various modifications of apparatus and of procedure.

Subcommittee B-7 on Viscosity and Float Tests (C. A. Benning, chairman) is studying the data from cooperative Engler viscosity tests to determine reproducibility of a proposed method, which will shortly be recommended for the approval of Committee D-4.

Subcommittee B-12 on Structural Properties of Mineral Aggregates (Stanton Walker, chairman) has been considering several important properties of aggregates for which there are no standardized methods of determination. These include the structural strength of coarse aggregate particles, void content of sands, characteristic shape of sand particles, and resistance to abrasion of fine aggregate. Other subjects before the subcommittee for active work are the contributions of different types of aggregate to the skid resistance of pavements and the evaluation of deleterious substances in concrete aggregates. Information is being assembled by the subcommittee on all these problems.

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[2] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

Subcommittee B-16 on Setting Qualities of Bituminous Materials (A. B. Cornthwaite, chairman) is continuing its search for a significant method for evaluating the drying or setting properties of bituminous materials. A preliminary investigation of a "rolling ball" apparatus has been completed and plans have been made for cooperative tests.

Subcommittee B-17 on Emulsion Tests (R. R. Thurston, chairman) has been assembling data for the purpose of determining reproducibility of the various tests for emulsified asphalts. Standard Method D 244 has been extensively revised editorially, and it is possible that further study involving cooperative testing will lead to other improvements.

Subcommittee B-19 on Accelerated Tests for Durability of Bituminous Materials (D. C. Taylor, chairman) has initiated a thorough study of a thin-film oven test which is used by several organizations for the evaluation of asphaltic materials.

Subcommittee B-24 on Penetration Tests (J. Y. Welborn, chairman) is considering use of the penetration test for asphalt cements as a means of specifying susceptibility to temperature changes in a practical range.

Subcommittee B-26 on Effect of Water on Bituminous Coated Aggregates (C. M. Hewett, chairman) has continued to investigate possible methods for evaluating the performance of bituminous coatings on aggregates in the presence of water. In addition to the radioactive tracer technique and photoelectric reflectance method mentioned last year, the subcommittee is considering the possible application of flame-photometry techniques to the measurement of "stripping."

Subcommittee C-4 on Specifications for Emulsified Asphalts (C. E. Proudley, chairman) is studying the relative importance of medium-setting type of emulsion and the various grades, having in mind a simplification and clarification of specifications.

Subcommittee C-12 on Bituminous Surface Treatments (J. O. Izatt, chairman) has prepared proposed specifications for aggregates suitable for use in multiple surface treatments and also is formulating a recommended practice on the use of materials for bituminous surface treatments.

Subcommittee D-2 on Highway Traffic Markers (H. F. Clemmer, chairman) has been recently reorganized and, after thorough discussion of the various phases of its field, is concentrating on assembling information and developing requirements for permanent types of traffic markers.

Subcommittee D-3 on Expansion Joint Materials (H. F. Clemmer, chairman) is conducting an extensive testing program on preformed fillers for expansion joints which may lead to a reconsideration of present ASTM methods of testing and specification requirements. Specifications for cold-application joint sealers of mastic or emulsion types are also being prepared by the subcommittee.

RESEARCH ACTIVITIES

In annual reports for the past several years, Committee D-4 has included a general summary of the more important research activities of its subcommittees. Continuing progress in the development of new methods of testing is demonstrated in the preceding review of subcommittee activities. Although investigations in progress have not resulted in recommendations this year for approval of additional testing methods and specifications, they have indicated a number of desirable revisions in existing methods and the need for thorough study of procedures accepted many years ago but now shown to be deficient in reproducibility and control features.

Properties of road materials recognized to be important but difficult to evaluate are receiving deserved attention. In particular, Subcommittees B-2, B-16, B-19, B-25, and B-26 are active primarily in fields of technology related to performance and service behavior of bituminous materials in which increasingly critical study and new approaches are necessary; correspondingly, Subcommittee B-12 is active in fields identified with the performance of mineral aggregates when used as highway materials.

This report has been submitted to letter ballot of the committee, which consists of 149 members; 114 members have returned their ballots, of whom 106 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

C. A. CARPENTER,
Chairman.

B. A. ANDERTON,
Secretary.

REPORT OF COMMITTEE D-5

ON

COAL AND COKE*

Committee D-5 on Coal and Coke held meetings in Atlantic City, N. J., on June 30, 1953, and in Washington, D. C., on February 3, 1954. The Advisory Subcommittee met the day prior to the main Committee meetings as well as in Chicago, Ill., on September 11, 1953.

During the year nine members were added to the committee, five members resigned, and two members died, resulting in a total membership of 65, of whom 21 are classed as consumers, 19 as producers, and 25 as general interest members. For voting purposes, there are 19 consumers, 18 producers, and 23 general interest members, resulting in a total voting membership of 60.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, W. W. Anderson.
Vice-Chairman, C. H. Sawyer.
Secretary, O. P. Brysch.

At the Advisory Subcommittee meeting in September, arrangements were completed for active participation of the United States at the third meeting of ISO/TC 27 on Solid Mineral Fuels, held in London on November 2 to 6, 1953. The U. S. delegates consisted of W. A. Selvig (leader), O. W. Rees, and W. M. Bertholf. At these meetings Mr. Bertholf presented a paper on "The Trend Theory in Coal Sampling." Mr. Selvig's attendance at the ISO/TC 27 meetings was supplementary to his subsequent duties at the eighth meeting of the Classification Working Party, Coal Committee, Economic Committee for Europe, held in Geneva, Switzerland, November 9 to 11, 1953.

Separate complete reports by all three delegates were made to Committee D-5 with recommendation for study and action.[1]

ISO/TC 27 has been requested by the Classification Working Party, Coal Committee, Economic Committee for Europe, to prepare international standards for certain analytical procedures and test methods for use in an international system of coal classification.

TENTATIVE REVISION OF STANDARDS

Committee D-5 recommends the following tentative revisions in two standards:

Standard Method of Test for Free-Swelling Index of Coal (D 720 - 46):[2]

Footnote 3.—Add an additional reference as follows:

> W. A. Selvig and W. H. Ode, "An Investigation of a Laboratory Test for Determination of the Free-Swelling Index of Coal, Revision of *R.I. 3989*," U. S. Bureau of Mines *Report of Investigation 4238* (1948).

Section 5.—Add the following new Paragraph (*c*):

> (*c*) Some coals give buttons that do not conform in shape to the standard profiles. For such coals, the maximum cross-sectional areas of the buttons may be measured, and the index de-

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13-18, 1954.

[1] A report on this meeting appears in ASTM BULLETIN, No. 198, May, 1954, p. 43.

[2] 1952 Book of ASTM Standards, Part 5.

termined from the relationship of the areas of the standard profiles to swelling indexes as shown in Fig. 1.[a] For measuring the cross-sectional areas, the buttons may be mounted on graph paper ruled into square centimeters and square millimeters, and the outlines of the buttons traced on the paper while viewing through the sight tube shown in Fig. 3. The mounting of the buttons may be done conveniently by means of modeling clay. The squares inside the outline may be counted, and fractions of squares along the boundary line estimated.

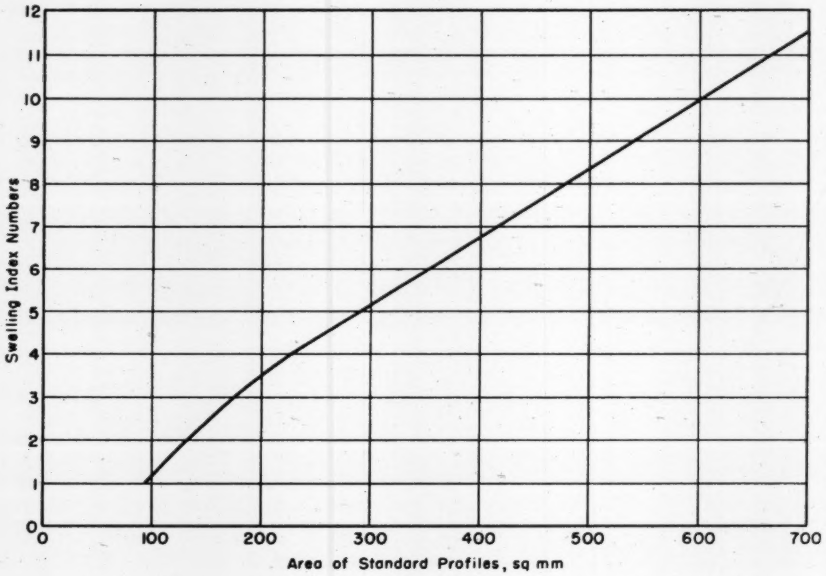

FIG. 1.—Relationship of Areas of Standard Profiles to Swelling Indexes.

Section 6.—Change to read as follows:

6. *Report.*—(*a*) The average swelling index of the series of four buttons, expressed to the nearest one-half unit, shall be reported.

(*b*) If the residue is a powder or if the button is nonswollen (swelling index of 1) and pulverizes under a weight of 500 g carefully lowered on it, the coal shall be designated as "nonagglomerating."

Standard Methods of Laboratory Sampling and Analysis of Coal and Coke (D 271 – 48).[2]—Replace the present Sections 32 to 37 relating to Ultimate Analysis of Carbon and Hydrogen with the following:

Carbon and Hydrogen

32. *Outline of Method.*—The determination of carbon and hydrogen is made by burning a weighed quantity of sample in a closed system and fixing the products of combustion in an absorption train after complete oxidation and purification from interfering substances. This method gives the total percentages of carbon and hydrogen in the coal as analyzed, and includes the carbon in carbonates and the hydrogen in the moisture and in the water of hydration of silicates.

33. *Apparatus.*—The apparatus used shall consist of an oxygen purifying train, a combustion unit and tube, and an absorption train.

(*a*) *Oxygen Purifying Train.*—It shall consist of the following units arranged as listed in the order of passage of oxygen:

(*1*) *First water absorber* shall be a container for the solid dehydrating reagent. It shall be so constructed that the oxygen must pass through a column of reagent adequate to secure water equilibrium equal to that secured in the prescribed absorption train. A container of large volume and long path of oxygen travel through the reagent will be found to be advantageous where many carbon and hydrogen determinations are made.

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[a] To take care of buttons whose cross-sectional area is greater than that of standard profile 9, the curve shown in Fig. 1 has been extended to include about 700 sq mm which is the maximum cross-sectional area of the silica crucibles used in the test.

(*2*) *Carbon dioxide absorber* shall be a container for solid carbon dioxide absorbing agent. It shall be constructed as described in Paragraph (*a*) Item (*1*) and shall provide for a column of reagent adequate to remove completely carbon dioxide.

(*3*) *Second water absorber* shall be as specified in Paragraph (*a*) Item (*1*).

(*4*) *Flow meter* shall be used to permit volumetric measurement of the rate of flow of oxygen during the determination. It shall be suitable for measuring flow rates within the range of 50 to 100 ml per min (STP). The use of a double stage pressure reducing regulator with gage and needle valve preceding the first water absorber is recommended to permit easy and accurate adjustment of the rate of flow.

(*b*) *Combustion Unit.*—The combustion unit shall consist of three electrically heated furnace sections, individually controlled, which may be mounted on rails for easy movement; the upper part of each furnace may be hinged so that it can be opened for inspection of the combustion tube. The three furnace sections shall be as follows:

(*1*) *Furnace section 1*, nearest the oxygen inlet end of the combustion tube, shall be approximately 13 cm long and shall be used to heat the inlet end of the combustion tube and the sample. It shall be capable of rapidly attaining an operating temperature of 850 to 900 C (Note 1).

(*2*) *Furnace section 2* shall be approximately 33 cm in length and shall be used to heat that portion of the tube filled with cupric oxide. The operating temperature shall be 850 ± 20 C (Note 1).

(*3*) *Furnace section 3* shall be approximately 23 cm long, and shall be used to heat that portion of the tube filled with lead chromate or silver. The operating temperature shall be 500 ± 50 C (Note 1).

(*c*) *Combustion Tube.*—The combustion tube shall be made of fused quartz or Vycor and shall have a nominal inside diameter which may vary within the limits of 19 to 22 mm and a minimum total length of 97 cm. The exit end shall be tapered down to provide a tubulated section for connection to the absorption train. The tubulated section shall have a length of 2 to 2.5 cm, an internal diameter of not less than 3 mm, and an external diameter of approximately 7 mm. The total length of the reduced end shall not exceed 6 cm. If a translucent fused quartz tube is used, a transparent section 10 cm long, located 25 cm from the oxygen inlet end of the tube, will be found convenient.

(*d*) *Combustion Boat.*—This shall be either glazed porcelain, fused silica, or platinum. Boats with internal dimensions of approximately 70 by 8 by 8 mm have been found convenient.

(*e*) *Absorption Train.*—The absorption train shall consist of the following units arranged as listed in the order of passage of oxygen:

(*1*) *Water absorber* shall have a capacity for 45 cu cm of solid reagent and a minimum length of gas travel through the reagent of 8 cm.[a]

(*2*) *Carbon dioxide absorber.*—If solid reagents are used for carbon dioxide absorption, the container shall be as described in Paragraph (*e*) Item (*1*). If a solution is used, the container shall be a Vanier bulb.

(*3*) *Guard tube* shall be a container as described in Paragraph (*e*) Item (*1*).

34. *Reagents.*—(*a*) *Oxygen,* 99.5 per cent purity or better shall be used (Note 5).

(*b*) *Combustion Tube Reagents:*

(*1*) *Cupric oxide,* wire form, ACS reagent grade, dust free.

(*2*) *Lead chromate,* cp, approximately 8 to 20-mesh size.

(*3*) *Silver gauze,* 99.9 per cent silver minimum purity, 20 mesh, made from approximately No. 27 B. & S. gage wire.

(*4*) *Copper gauze,* 99.0 per cent copper minimum purity, 20 mesh made from approximately No. 26 B. &. S. gage wire.

(*c*) *Purification and Absorption Train Reagents:*

(*1*) *Water absorbent.*—Anhydrous magnesium perchlorate, anhydrous calcium sulfate, or calcium chloride, of approximately 8 to 45-mesh size (Note 2).

(*2*) *Carbon dioxide absorbent.*—If a solid reagent is used, it shall be sodium or potassium hydroxide impregnated in an inert carrier of approximately 8 to 20-mesh size. Use of soda lime in place of the above or in admixture with them is permissible (Note 3). If a solution is used, it shall be 30 per cent by weight potassium hydroxide ACS reagent grade.

35. *Preparation of Apparatus:* (*a*) *Combustion Tube Packing.*—To insure complete oxidation of combustion products and complete removal of interfering substances such as oxides of sulfur, the combustion tube shall be packed with cupric oxide and lead chromate or silver. The arrangement and lengths of the tube fillings and separating plugs shall be as shown in Fig. 8. It is recommended that the tube be placed in a

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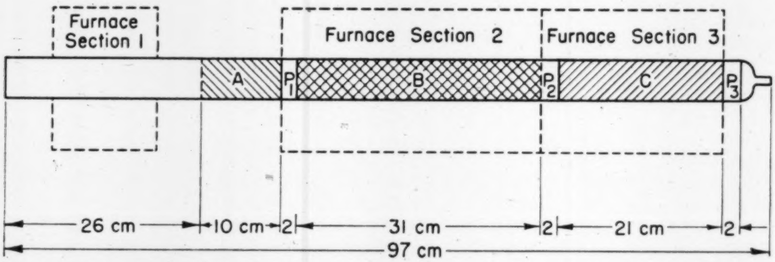
[a] Glass-stoppered containers such as the Nesbitt, Schwartz U-tube and the Stetser-Norton bulbs have been found satisfactory.

vertical position (constricted end downward) for packing. When filling the tube with lead chromate, any residual reagent adhering to the walls of the empty portion of the tube must be removed. When silver is used as a tube filling, the required length of filling may be prepared conveniently from three or four strips of silver gauze 15 to 20 cm long, by rolling each strip into a cylindrical plug and inserting the strips end-to-end in the tube (Note 4).

(*b*) *Absorption Train:*

(*1*) *Water absorber* shall be a container filled with a permissible solid desiccant by adding the required amount in small portions and settling each portion by gentle tapping between additions. A glass wool plug shall be placed between the reagent and the absorber outlet to prevent loss of reagent "dust."



A.—Clear fused quartz section (optional) when a translucent quartz tube is used.
B.—Cupric oxide filling.
C.—Lead chromate or silver filling.
P_1, P_2, P_3—oxidized copper gauze plugs.

NOTE.—All dimensions are given in centimeters. When furnace sections longer than those specified in Section 33(*b*) are to be used, changes in the above dimensions shall be in accordance with the provisions of Note 4.

FIG. 8.—Arrangement of Tube Fillings for Combustion Tube.

(*2*) *Carbon dioxide absorber.*—If a solid reagent is used for the retention of carbon dioxide, the absorber shall be filled as described in Paragraph (*b*) Item (*1*). A layer or "cap" of desiccant shall be placed in the outlet section of the container and shall be the same as that used in the water absorber. This layer shall have a bulk volume not less than one-fourth nor more than one-third of the combined volume of both reagents. If a liquid absorbent is used, the inner tube of the Vanier bulb shall be filled with the same desiccant used in the water absorber. A glass wool plug shall be placed in the outlet section of the container to prevent loss of reagent "dust."

(*3*) *Guard tube* shall be packed with equal volumes of the water absorbent and a solid carbon dioxide absorbent.

(*c*) *Connections.*—To insure a closed system from the supply tank of oxygen to the guard tube at the end of the absorption train, it is recommended that all connections be glass to glass or glass to quartz butt joints with short lengths of flexible tubing as seals. The connection between the purification train and the combustion tube may be made by means of a rubber stopper or other suitable device. All connections shall be gas tight. No lubricant shall be used for making tubing connections in the absorption train.

(*d*) *Conditioning of Apparatus:*

(*1*) *Newly packed combustion tube.*—A sample of coal or coke shall be burned as described in Section 36, except that the products of combustion need not be fixed in a weighed absorption train.

(*2*) *Used combustion tube.*—After any extended shut down, one day or more, the combustion train shall be tested under procedure conditions, but without burning a sample, for 40 min with weighed absorption bulbs connected. A variation of not more than 0.5 mg of either bulb shall be considered satisfactory (Note 5).

(*3*) *Absorption train.*—Freshly packed absorber and guard tubes shall be conditioned by burning a sample of coal or coke as described in Section 36, except that tube weights need not be determined.

(*4*) *Standard checks* shall be made frequently, particularly when intermittent use of the combustion train is common or when any changes have been made in the system. A standard substance of certified analysis, such as benzoic acid or sucrose as furnished by the National Bureau of Standards shall be burned as described in Section 36. A variation from the theoretical of not more than 0.07 per cent for hydrogen nor more than 0.30 per cent for carbon shall be considered satisfactory.

36. ***Procedure.***—After the combustion tube

and absorbers have been conditioned as prescribed in Section 35, the test shall be made as follows:

(*a*) *Absorption Train.*—The absorption tubes shall be brought to room temperature near the balance for 15 to 20 min, vented momentarily to atmosphere, wiped with a chamois or lint-free cloth in the areas where handled, and weighed to the nearest 0.1 mg using a similar bulb as counterpoise on the balance.

(*b*) *Sample.*—Approximately 0.2 g (weighed to the nearest 0.1 mg) of air-dry sample ground to pass a 250-micron (No. 60) or finer sieve, shall be weighed into a combustion boat.

(*c*) *Sample Analysis.*—With furnace sections 2 and 3 at specified temperatures and positioned as shown in Fig. 8, perform the following operations in rapid succession in the order listed: (*1*) if a conventional type of sample heating furnace is used for heating section No. 1, place it so that its left-hand edge is about 10 cm from the oxygen inlet end of the combustion tube; (*2*) attach the weighed absorption train to the tube; (*3*) push the sample boat into the tube to a point within approximately 2 cm from plug P_1; (*4*) close the tube and adjust the oxygen flow to a rate of 50 to 100 ml per minute (STP) being the same as used in blanking, Section 35 (*d*) Item (*2*); and (*5*) apply full heat to heating section No. 1 to bring it to an operating temperature of 850 to 900 C as rapidly as possible. Move the heater slowly toward the boat so that it completely covers the boat and is brought into contact with heating section No. 2 in a period of 10 to 20 min (Note 6). Allow it to remain in this position for an additional 5 to 10 min, and then shut-off the heat and return the sample heater to its original position. Continue the flow of oxygen through the tube for 10 min (Note 7), close the absorbers under a positive pressure of oxygen, and detach them from the train. Remove the absorbers to the vicinity of the balance, allow them to cool to room temperature for 15 to 20 min, vent momentarily to atmosphere, wipe them with a chamois or lint-free cloth in the areas handled, and finally weigh them to the nearest 0.1 mg using the identical absorber of Paragraph (*a*) as a counterpoise. While the absorbers are cooling, it is recommended that the ash remaining in the combustion boat be examined for traces of unburned carbon which, if present, will nullify the determination.

37. *Calculation.*—The percentage of carbon (Note 8) and hydrogen shall be calculated as follows:

Hydrogen, per cent

$$= \frac{11.19 \times \text{(increase in wt of } H_2O \text{ absorption bulb)}}{\text{wt of sample}}$$

Carbon, per cent

$$= \frac{27.289 \times \text{(increase in wt of } CO_2 \text{ absorption bulb)}}{\text{wt of sample}}$$

NOTE 1.—Combustion tube temperatures shall be measured by means of a thermocouple placed immediately adjacent to the tube near the center of the appropriate tube section.

NOTE 2.—Trade names of the listed permissible dehydrating reagents are: Anhydrone or Dehydrite, Drierite, and calcium chloride.

NOTE 3.—Trade names of the sodium and potassium hydroxide permissible solid carbon dioxide absorbing reagents are: Ascarite, Caroxite, and Mikohbite. If soda lime is used in admixture with any of the foregoing, it should not exceed 30 per cent by weight of the total reagent. In using Ascarite it may be necessary to add a few drops of water to this reagent to assure complete absorption of carbon dioxide.

NOTE 4.—Longer furnaces with appropriate lengths of tube packing will be satisfactory.

NOTE 5.—If the blank tests for flow indicate interfering impurities in the oxygen supply by consistent weight-gain in the absorption bulbs, these impurities shall be eliminated by using a preheater furnace and tube, filled with cupric oxide. This preheater furnace shall be operated at 850 ± 20 C and shall be inserted in series between the supply tank of oxygen and the purification train.

NOTE 6.—Some variation in operating technique and heater manipulation may be permitted here at the discretion of the analyst, provided that it is conducive to a gradual and controlled release of volatile matter. Conditions which lead to visible burning (flame combustion) of the sample shall be avoided.

NOTE 7. Since water may condense in the cooler outlet end of the combustion tube or in the inlet arm of the water absorber, the use of an external or internal heat conducting device (a metal heat bridge) is recommended to prevent such condensation or promote re-evaporation during this flushing period.

NOTE 8.—It is recognized that formation of oxides of nitrogen during the combustion procedure may lead to slightly high results for carbon. However, extensive study of this effect by five laboratories led to the conclusion that error so incurred would not be significant in commercial application. In certain research applications, where accuracy of a higher order is required, means of removing oxides of nitrogen prior to water and carbon dioxide absorption should be included.

The recommendations appearing in

this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[3]

ACTIVITIES OF SUBCOMMITTEES

Subcommittee XIII on Coal Sampling (H. F. Hebley, chairman) arranged for a Symposium on Coal Sampling to be presented at the Annual Meeting in Chicago on June 14, 1954. The Symposium includes the following eight papers:[4]

"The Development of the Theoretical Basis of Coal Sampling," by W. M. Bertholf, Colorado Fuel and Iron Corp.

"A Test on a Slotted Revolving Cylinder Coal Sampler," by A. O. Blatter, Union Electric Co. of Missouri.

"Tests of Accuracy of a Mechanical Coal Sampler," by R. L. Coryell, F. J. Schwerd, and E. J. Parente, Consolidated Edison Co. of New York.

"Multi-Lot Sampling, the Accuracies in Sampling of Large Coal Shipments by Applications of the Variance Concept," by T. A. Miskimen and R. S. Thurston, American Gas and Electric Corp.

"Tests of the Geary-Jennings Sampler at Cabin Creek," by W. M. Bertholf, Colorado Fuel and Iron Corp., and W. L. Webb, American Gas and Electric Corp.

"Some Recent British Work on Coal Sampling," by R. C. Tomlinson, National Coal Board.

"The Variances of Reduction and Analysis," by W. W. Anderson, Commercial Testing and Engineering Co., and M. L. Sutherland, Statistical Consultant.

"Tests on the Binomial Sampling Theory," by Jan Visman, Dept. of Mines and Technical Surveys, Canada.

Subcommittee XV on Plasticity and Swelling of Coal (Michael Perch, chairman) prepared the tentative revision of the Standard Method of Test for Free-Swelling Index of Coal (D 720 - 46), covering the addition of an alternate method of measurement of odd-shaped coke buttons by an equivalent area method.

A task group of this subcommittee is preparing a revision of the Standard Method of Test for Cubic Foot Weight of Crushed Bituminous Coal (D 291 - 29) to incorporate the Koppers cone method of loading the measuring box.

Subcommittee XXI on Methods of Analysis (O. W. Rees, chairman).—Section A on Proximate Analysis is continuing work on the volatile matter determination with special emphasis being placed on investigation of the methods under review by ISO/TC 27.

In connection with the work on a method for determination of inherent moisture, the Bureau of Mines *Report of Investigation 4968*, entitled "Determination of Moisture-Holding Capacity (Bed Moisture) of Coal for Classification by Rank," by W. A. Selvig and W. H. Ode, is being reviewed, and copies of this paper have been furnished to ISO/TC 27.

Copies of Bureau of Mines *Report of Investigation 4969*, entitled "Determination of Moisture in Low-Rank Coals," by John Goodman, Manuel Gomez, and V. F. Parry, were also furnished to ISO/TC 27 for aid in the study of the general problem of determination of moisture.

Section B on Ultimate Analysis prepared the tentative revision of the Standard Methods of Laboratory Sampling and Analysis of Coal and Coke (D 271 - 48), relating to the procedures for carbon and hydrogen determination.

Revision of the method for nitrogen determination is in its fifth version, and Section B hopes to submit this method to letter ballot in the coming year.

Section C on Miscellaneous Analyses

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[3] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

[4] Issued as separate publication *ASTM STP No. 162.*

is continuing its study of the fusibility of ash determination with special emphasis on study of results under oxidizing conditions.

This report has been submitted to letter ballot of the committee, which consists of 60 voting members; 57 members returned their ballots, of whom 54 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

W. W. ANDERSON,
Chairman.

O. P. BRYSCH,
Secretary.

REPORT OF COMMITTEE D-6

ON

PAPER AND PAPER PRODUCTS*

Committee D-6 on Paper and Paper Products held two meetings during the year: on July 1, 1953, in Atlantic City, N. J., and on February 19, 1954, in New York City. The Advisory and other subcommittees held meetings in conjunction with the main committee.

At the present time, the committee consists of 88 members, of whom 72 are voting members; 30 are classified as producers, 24 as consumers, and 34 as general interest members.

The subcommittee structure was revised during the year and much of the subcommittee effort has been directed toward organizing the work on the new basis.

Plans for a symposium on Tensile Testing of Nonmetallic Sheet Materials during the 1955 Annual Meeting are moving forward under Committee E-1 on Methods of Testing as recommended last year by Committee D-6.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, W. R. Willets.
Vice-Chairman, T. J. Gross.
Secretary, R. H. Carter.

ADOPTION OF TENTATIVES AS STANDARD

The committee recommends that the following tentatives be approved for reference to letter ballot of the Society for adoption as standard:

Tentative Methods of Test for Flat Crush of Corrugated Paperboard (**D 1225 - 52 T**).[1]

Tentative Method of Test for Water Resistance of Paper, Paperboard, and Other Sheet Materials by the Dry-Indicator Method (**D 779 - 52 T**),[1] with revisions as indicated:

Section 2.—Add a new Section 2 on Significance of Test as follows, and renumber the present Section 2 and subsequent sections:

> 2. The test measures the resistance of a sheet of paper to the penetration of water from one face to the other. The test is empirical in that the end point is interpreted by the technician. It is of value in all cases where paper or a paper container comes into contact with water on one face.

Section 7.—Revise Section 7 (new Section 8) to read as follows:

> 8. Average test results by experienced operators should agree within 15 per cent.

Tentative Methods of Test for Ply Adhesion of Paper (**D 825 - 52 T**),[1] with revisions as indicated:

Section 2.—Add a new Section 2 on Significance of Test as follows, and renumber the present Section 2 and subsequent sections:

> 2. The method measures a fundamental property of the sheet of paper as made on a cylinder machine. It is useful in determining how well the different plies are bonded and adhere to each other. Poor adhesion would cause the plies to separate and destroy the sheet. The test is reproducible within ±10 per cent.

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13–18, 1954.

[1] 1952 Book of ASTM Standards, Part 7.

Tentative Methods of Test for Zinc and Cadmium in Paper (**D 1224 – 52 T**),[1] with revisions as indicated:

Section 2.—Add a new Section 2 on Significance of Test as follows, and renumber the present Section 2 and subsequent sections:

> 2. Fluorescent zinc and cadmium pigments are added to some printing papers to cause them to fluoresce. The method measures the amount of the zinc or cadmium present and is useful in determining if these pigments have been added to the paper.

Section 10(a).—Add the following footnote to be indicated against the words "porcelain plate" in line 14:

> Avoid the transfer of any uranyl ions into the zinc solution.

TENTATIVES CONTINUED WITHOUT REVISION

The committee recommends that the following nine tentative methods which have stood for two years without revision be continued as tentative:

Tentative Method of Test for:

Puncture and Stiffness of Paperboard, Corrugated and Solid Fiberboard (D 781 – 44 T),
Analytical Filter Papers (D 981 – 51 T),
Stretch of Paper and Paper Products under Tension (D 987 – 48 T),
Water Vapor Permeability of Paper and Paperboard (D 988 – 51 T),
Fiber Analysis of Paper and Paperboard (D 1030 – 49 T),
Chloride Content of Paper and Paper Products (D 1161 – 51 T),
Pinholes in Glassine and Other Greaseproof Papers (D 1221 – 52 T),
Contrast Gloss of Paper at 57.5 Deg. (D 1222 – 52 T), and
Specular Gloss of Paper at 75 Deg. (D 1223 – 52 T).

The recommendations appearing in the report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[2]

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Sampling and Conditioning (R. H. Lace, chairman) has been reviewing the Standard Method of Sampling Paper and Paper Products (D 585 – 42) in light of a proposal submitted by Subcommittee IV, and various textile methods of sampling in an effort to develop a method of sampling that is accurate as well as feasible.

Subcommittee II on Chemical Test Methods (E. G. Ham, chairman) has now been reorganized and work is being done which may lead to proposed revisions in the Method of Test for Fiber Analysis of Paper and Paperboard (D 1030 – 49 T) and the Method of Test for Chloride Content of Paper and Paper Products (D 1161 – 51 T).

Subcommittee III on Physical Test Methods for Paper (R. B. Hobbs, chairman) has now been reorganized and revisions of the Method of Test for Bursting Strength of Paper (D 774 – 46) and Method of Test for Basis Weight of Paper and Paper Products (D 646 – 50) are about ready for submission to main committee ballot. Work is being done which may lead to proposed revisions in the Methods of Testing Analytical Filter Papers (D 981 – 51 T), Method of Test for Stretch of Paper and Paper Products (D 987 – 48 T), Method of Test for Pinholes in Glassine and other Greaseproof Papers (D 1221 – 52 T), Method of Test for Resistance of Paper to Passage of Air (D 726 – 48), and Method of Test for Tensile Breaking Strength of Paper and Paper Products (D 828 – 48).

Subcommittee IV on Physical Test Methods for Container Board (W. B. Lincoln, Jr., chairman) plans further analysis and possibly added tests as a result of the round-robin testing already completed in conjunction with proposed revisions of the Method of Test for Puncture and Stiffness of Paperboard, Corrugated and Solid Fiberboard

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[2] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

(D 781 - 44 T). This is complicated by the fact that the instrument is now being manufactured by a different company and changes may be made in it. Work is under way on an immersion test and on corrugating medium testers, and a survey is being conducted to determine the degree of interest in several other tests.

Subcommittee V on Specifications for Paper (P. F. Wehmer, chairman) is preparing a specification on Heavy Duty Shipping Sack Kraft Paper.

Subcommittee VI—Editorial (L. S. Reid, chairman) is reviewing existing methods with a view towards making the form more uniform. All future new and revised methods and specifications will be reviewed, edited, and "significance" paragraphs added where necessary by this subcommittee before being sent to letter ballot of the main committee.

This report has been submitted to letter ballot of the committee, which consists of 72 voting members; 43 members returned their ballots, of whom 38 voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

W. R. WILLETS,
Chairman.

R. H. CARTER,
Secretary.

REPORT OF COMMITTEE D-7

ON

WOOD*

Committee D-7 on Wood met in Chicago, Ill., on March 15 and 16, 1954. The following subcommittee meetings preceded the meeting of the main committee: Subcommittee I on Specifications for Timber, Subcommittee VII on Wood Poles and Cross Arms, and Subcommittee XV on Structural Fiberboards.

Twelve applicants were elected to membership on the committee during the year. There were two resignations and one death.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, L. J. Markwardt.
Secretary, L. W. Smith.

NEW TENTATIVES

The committtee recommends that the following specifications and methods of chemical analysis be accepted for publication as tentative as appended hereto:[1]

Tentative Specifications for:

Modified Wood.
Ammoniacal Copper Arsenite.

Tentative Methods of:

Chemical Analysis of Ammoniacal Copper Arsenite.

REVISION OF TENTATIVE

The committee recommends that the Tentative Specification for Round Timber Piles (**D 25 - 53 T**),[2] be revised as indicated and continued as tentative:

Section 3(a).—In line 4, delete the words "in most cases."

Section 11.—Change Note 11 to read:

> NOTE 11.—Long piles for driving to lighter bearing values may be bought under a more liberal alternative specification as follows: "A straight line from the center of the butt to the center of the tip may lie partly outside the body of the pile, but the maximum distance between the line and the pile shall not exceed one-half per cent of the length of the pile or 3 in., whichever is smaller."

Section 11(b).—Change to read as follows: (*b*) Class A or B piles shall be free from short crooks in which the deviation from straightness in any 5 ft of length anywhere exceeds $2\frac{1}{2}$ in. (Fig. 1). Short crooks shall also comply with the requirements for sweep in Paragraph 11(*a*).

Section 13.—Change the first two sentences to read as follows:

> Sound knots in Class A or B piles 50 ft or less in length, and in three-quarters of the length from the butt of Class A or B piles longer than 50 ft, shall be no larger than 4 in. or one-third of the diameter of the pile at the point where they occur, whichever is the smaller. Sound knots in the remaining one-quarter of the length of piles longer than 50 ft shall be no larger than 5 in. or one-half of the diameter of the pile at the point where they occur, whichever is the smaller.

Section 16(b).—Change to read as follows:

> (*b*) Class C piles shall be free from short crooks in which the deviation from straightness in any 5 ft of length anywhere exceeds two and one-half in. (Fig. 1). Short crooks shall also comply with the requirements for sweep in Paragraph 16(*a*).

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13–18, 1954.

[1] The new tentatives were accepted by the Society and appear in the 1954 Supplement to Book of ASTM Standards, Part 4.

[2] 1953 Supplement to Book of ASTM Standards, Part 4.

TENTATIVES CONTINUED WITHOUT REVISION

The committee recommends that the following tentatives be continued in their present status pending further study:

Tentative Methods of:

Establishing Structural Grades of Lumber (D 245 - 49 T),
Static Tests of Wood Poles (D 1036 - 49 T),
Test for Ash in Wood (D 1102 - 50 T),
Test for Alpha Cellulose in Cellulosic Materials (D 1103 - 50 T),
Test for Holocellulose in Wood (D 1104 - 50 T),
Test for Preparation of Extractive-Free Wood (D 1105 - 50 T),
Test for Lignin in Wood (D 1106 - 50 T),
Test for Alcohol-Benzene Solubility of Wood (D 1107 - 50 T),
Test for Ether Solubility of Wood (D 1108 - 50 T),
Test for One Per Cent Caustic Soda Solubility of Wood (D 1109 - 50 T),
Test for Water Solubility of Wood (D 1110 - 50 T), and
Test for Methoxyl Groups in Wood and Related Materials (D 1165 - 51 T).

The recommendations appearing in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[3]

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Specifications for Timber (Lyman W. Wood, chairman) has continued work on the Tentative Specification for Round Timber Piles (D 25 - 53 T) and the revision recommended above represents the subcommittee's conclusions with respect to this specification. The subcommittee next intends to prepare a revision of the Tentative Methods for Establishing Structural Grades of Lumber (D 245 - 49 T).

Subcommittee II on Laminated Timber (F. J. Hanrahan, chairman) has had under review the Standard Method of Test for Integrity of Glue Joints in Laminated Wood Products for Exterior Service (D 1101 - 53). No changes or modifications are recommended at this time.

Subcommittee VI on Timber Preservatives (R. H. Bescher, chairman) has developed the Tentative Specifications for Ammoniacal Copper Arsenite and the Tentative Methods for Chemical Analysis of Ammoniacal Copper Arsenite, which are recommended for publication as tentative.

Subcommittee VII on Wood Poles and Cross Arms (R. P. A. Johnson, chairman).—The principal activity of this subcommittee has been the inauguration of the ASTM Wood Pole Research Program which has five broad objectives as follows:

1. To compare the crib method with the machine method of testing full-length poles. ASTM standards covering both methods have been prepared. The program provides for a comparison of results obtained by the two methods.

2. To determine the strength of full-size poles of the most important pole species, as a basis for confirming or revising the allowable design stresses now in use for the several species, as may be found necessary.

3. To determine the relation of the strength of small clear specimens of a species of wood to the strength of poles of the same species, as a means of establishing whether tests of small clear specimens can be used in place of the more expensive tests of full-size poles as a basis for establishing design stresses.

4. To obtain new information on the effects of knots, spiral grain, and other irregularities on the strength of poles.

5. To study the effect of the commonly used preservative treating methods on the breaking strength of treated poles.

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[3] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

The entire program involves the testing of some 600 full-size poles and some 15,000 tests of small clear specimens cut from them. It is expected that the entire program will extend over a two-year period, and the cost is estimated at $160,000. Contributions to the program are being solicited from pole producers, pole treaters, and pole users. Sufficient funds have been received during the first year to initiate the program but additional contributions will be necessary to insure the completion of the program.

The first species tested under the research program was western larch. Southern pine poles are now being collected for continuation of the tests which will be followed by tests of Douglas fir, Western red-cedar, and lodgepole pine.

Subcommittee VIII on Modified Wood and Wood-Base Material (W. G. Youngquist, chairman) has developed the Tentative Specifications for Modified Wood, which as noted earlier in this report are recommended for publication as tentative.

Subcommittee XIII on Durability and Exposure has a new chairman, R. M. Lindgren.

Subcommittee XIV on Methods of Chemical Analysis (G. J. Ritter, chairman) has developed no new or improved methods of chemical analysis during the past year. The tentative methods already published are recommended for continuance as tentative.

Subcommittee XV on Structural Fiberboards (Wayne C. Lewis, chairman) has held two meetings during the past year. It has defined the scope of its activities and has two task groups working on (1) nomenclature and definitions, and (2) survey of test methods.

This report has been submitted to letter ballot of the committee, which consists of 85 voting members; 64 members returned their ballots, of whom 59 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

L. J. MARKWARDT,
Chairman.

L. W. SMITH,
Secretary.

REPORT OF COMMITTEE D-8

ON

BITUMINOUS WATERPROOFING AND ROOFING MATERIALS*

Committee D-8 on Bituminous Waterproofing and Roofing Materials held two meetings during the year: one in Atlantic City, N. J., on July 1, 1953, and the other in Washington, D. C., on February 4, 1954.

The committee suffered loss through the resignation of Mr. E. I. Manning of Esso Standard Oil Co.

The membership, consisting of 75 voting members, is composed of 46 producers, 12 consumers, and 17 general interest members.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, H. R. Snoke.

Vice-Chairman, H. W. Greider.

Secretary, G. W. Robbins.

All of the standards and tentatives for which Committee D-8 is responsible have been reviewed and recommendations concerning them are set forth in this report.

NEW TENTATIVES

Committee D-8 recommends that the following specification and method of test be accepted for publication as tentative as appended hereto:[1]

Tentative Specification for Woven Burlap Fabrics Saturated with Bituminous Substances for Use in Waterproofing.

Tentative Method of Test for Staining Properties of Asphalts (Modified Pressure Method).

REVISION OF TENTATIVE

The committee recommends that the following tentatives be revised as indicated and continued as tentative:

Tentative Methods of Testing Asphalt Roll Roofing, Cap Sheets, and Shingles (**D 228 – 48T**):[2]

Section 2.—Change paragraph for "Type X" to read as follows:

> Type X.—A single thickness of asphalt-saturated felt coated with an asphaltic coating which may be compounded with a fine mineral stabilizer and surfaced with powdered mineral matter such as talc or mica.

Section 2.—Change paragraph for "Type Z" to read as follows:

> Type Z.—A single thickness of asphalt-saturated felt coated on the weather side for approximately one-half its width with an asphalt coating which may be compounded with a fine mineral stabilizer and the coated portion surfaced with coarse mineral granules.

Section 9.—Change the formula to read as follows:

$$\text{Weight, lb. per 100 sq. ft.} = \frac{A}{B} \times 30.0$$

where:

A = weight of 30-in. sample in ounces,

B = width of 30-in. sample in inches, and

30 = factor for converting ounces per measured unit area (30 in. × B) to pounds per 100 sq. ft."

Wherever the unit area of "108 sq. ft." is used in this specification, change to "100 sq. ft."

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13–18, 1954.

[1] The new tentatives were accepted by the Society and appear in the 1954 Supplement to Book of ASTM Standards, Part 3.

[2] 1952 Book of ASTM Standards, Part 3.

Section 23.—Change the second sentence to read as follows:

After cooling, add to each ash approximately five times its weight of saturated ammonium carbonate solution, let digest for one hour at room temperature in a covered beaker or crucible, dry in an oven at 105 C (221 F) to constant weight, and record that weight as "ash."

Specifications for Asphalt Roofing Surfaced with Mineral Granules (**D 249 – 50 T**):[2]

Section 1.—Change to read as follows:

1. These specifications cover asphalt roofing in sheet form, 36 in. in width, composed of roofing felt saturated and coated on both sides with asphalt and surfaced on the weather side with mineral granules.

TENTATIVE REVISION OF STANDARDS

The committee recommends the revisions of the following standards as indicated for publication as tentative:

Specifications for Asphalt-Saturated Roofing Felt for Use in Waterproofing and in Constructing Built-Up Roofs (**D 226 – 47**):[2]

Section 9.—Change the second and third items of the table to read as follows:

	15-lb. Type	30-lb. Type
Area of roll, min. sq. ft.	(Note 1)	216
Loss on heating at 105 C. (221 F.) for 5 hr., max., per cent	4	4

NOTE 1.—The number of squares or square feet per roll of 15-lb. type shall be on the basis of agreement between the buyer and seller.

Specifications for Coal Tar Saturated Roofing Felt for Use in Waterproofing and in Constructing Built-Up Roofs (**D 227 – 47**):[2]

Section 8.—Change the second item in the table to read as follows:

Area of Roll	Shall be based on agreement between buyer and seller.

Specifications for Asphalt-Saturated Asbestos Felts for Use in Waterproofing and in Constructing Built-Up Roofs (**D 250 – 47**):[2]

Section 9.—Change the second item in the table to read as follows:

	15-lb. Type	30-lb. Type
Area of roll, min., sq. ft.	(Note 1)	216

NOTE 1.—The number of squares or square feet per roll of 15-lb. type shall be on the basis of agreement between the buyer and seller.

Specifications for Asphalt Shingles Surfaced with Mineral Granules (**D 225 – 51**):[2]

Table I.—After "Weight of exposed area per 100 sq. ft." add new requirements as follows:

	Type I		Type II		Type III	
	Max., lb.	Min., lb.	Max., lb.	Min., lb.	Max., lb.	Min., lb.
Weight of unexposed area per 100 sq. ft.	....	76.9	....	87.0	....	60.0

ADOPTION OF TENTATIVE AS STANDARD

The committee recommends that the Tentative Definitions of Terms Relating to Bituminous Waterproofing and Roofing Materials (**D 1079 – 52 T**)[2] be approved for reference to letter ballot of the Society for adoption as standard without change.

REVISION OF STANDARDS, IMMEDIATE ADOPTION

The committee recommends for immediate adoption revisions of the following three standards. The revisions are listed below and the committee requests the necessary nine-tenths affirmative vote at the Annual Meeting in order that these recommendations may be referred to letter ballot of the Society.

Specifications for Asphalt Shingles Surfaced with Mineral Granules (**D 225 - 51**):[2]

Section 1(a).—Change to read as follows:

1. (*a*) These specifications cover asphalt roofing in shingle form, composed of roofing felt saturated and coated on both sides with asphalt and surfaced on the weather side with mineral granules.

Specification for Asphalt Roofing Surfaced With Powdered Talc or Mica (**D 224 - 52**):[2]

Section 1.—Change to read as follows:

1. These specifications cover asphalt roofing in sheet form, 36 in. in width, composed of roofing felt saturated and coated on both sides with asphalt and surfaced on the weather side with powdered mineral matter such as talc or mica.

Specification for Asphalt Siding Surfaced With Mineral Granules (**D 699 - 51**):[2]

Section 1(a).—Change to read as follows:

1. (*a*) These specifications cover asphalt siding in shingle form, composed of roofing felt saturated and coated on both sides with asphalt and surfaced on the weather side with mineral granules.

TENTATIVES CONTINUED WITHOUT REVISION

Committee D-8 recommends that the following tentatives which have been published by the Society for two or more years be continued as tentative, since they are being reviewed for possible revision to be recommended before the next Annual Meeting:

Tentative Specification for:

Asphalt Insulating Siding Surfaced with Mineral Granules (D 1226 - 52 T).

Tentative Method of:

Testing Asphalt Insulating Siding Surfaced with Mineral Granules (D 1228 - 52 T),

Sampling Bituminous Materials (D 140 - 52 T), and

Testing Asphalt-Base Emulsions for Use as Protective Coatings for Built-Up Roofs (D 1167 - 51 T).

Tentative Recommended Practice for:

Accelerated Weathering Test of Bituminous Materials (D 529 - 39 T).

AMERICAN STANDARDS

The following standards under the jurisdiction of Committee D-8 are recommended for submittal to the American Standards Association for approval as American Standard:

Specifications for:

Coal-Tar Pitch for Roofing, Dampproofing, and Waterproofing (D 450 - 41),

Coal-Tar Pitch for Steep Built-Up Roofs (D 654 - 49),

Woven Cotton Fabrics Saturated with Bituminous Substances for Use in Waterproofing (D 173 - 44),

Asphalt-Saturated Roofing Felt for Use in Waterproofing and in Constructing Built-Up Roofs (D 226 - 47),

Coal-Tar Saturated Roofing Felt for Use in Waterproofing and in Constructing Built-Up Roofs (D 227 - 47),

Asphalt-Saturated Asbestos Felts for Use in Waterproofing and in Constructing Built-Up Roofs (D 250 - 47),

Asphalt-Saturated and Coated Asbestos Felts for Use in Constructing Built-Up Roofs (D 655 - 47),

Primer for Use with Asphalt in Dampproofing and Waterproofing (D 41 - 41), and

Creosote for Priming Coat with Coal-Tar Pitch in Dampproofing and Waterproofing (D 43 - 41).

Methods of:

Test for Steam Distillation of Bituminous Protective Coatings (D 255 - 28),

Sampling and Testing Felted and Woven Fabrics Saturated with Bituminous Substances for Use in Waterproofing and Roofing (D 146 - 47),

Test for Kerosine Number of Roofing and Flooring Felt by the Vacuum Method (D 727 - 45),

Test for Sieve Analysis of Granular Mineral Surfacing for Asphalt Roofing and Shingles (D 451 - 40), and

Test for Sieve Analysis of Nongranular Mineral Surfacing for Asphalt Roofing and Shingles (D 452 - 40).

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[3]

This report has been submitted to letter ballot of the committee, which consists of 75 members; 50 members returned their ballots, of whom 47 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

H. R. SNOKE,
Chairman.

G. W. ROBBINS,
Secretary.

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[3] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

REPORT OF COMMITTEE D-9

ON

ELECTRICAL INSULATING MATERIALS*

Committee D-9 on Electrical Insulating Materials held two meetings during the year: in Atlantic City, N. J., on September 29 to October 2, 1953, and in Roanoke, Va., on March 24 to 26, 1954. A meeting of the committee had been held during the Annual Meeting of the Society in Atlantic City, N. J., on June 29 to July 1, 1953.

At these meetings action was taken on several new methods, revisions of existing tentatives, and changes in certain of the standards under the jurisdiction of Committee D-9. Also, progress was made on other projects under study by the various subcommittees, as mentioned later in the report.

At the meeting on July 1, 1953, Subcommittee XIII on Mechanical Properties was discontinued.

Committee D-9 has unanimously elected R. F. Field as Honorary Member of the committee in appreciation of his long term of service and his many contributions to the committee's work.

RECOMMENDATIONS ACCEPTED BY THE ADMINISTRATIVE COMMITTEE ON STANDARDS

Subsequent to the 1953 Annual Meeting, Committee D-9 presented to the Society through the Administrative Committee on Standards the following recommendations:

Tentative Specifications for:

Electrical Insulating Paper, Interlayer Type (D 1305 - 54 T).

Revision of Tentative Methods of:

Testing Hydrocarbon Waxes Used for Electrical Insulation (D 1168 - 51 T).

Test for Power Factor and Dielectric Constant of Electrical Insulating Materials (D 150 - 47 T).

The new Tentative Specifications D 1305 and the revised Methods D 1168 were accepted by the Standards Committee on February 23, 1954, and are appended hereto.[1]

The revised Tentative Methods D 150 were accepted on May 18, 1954, and they appear in the 1954 Supplement to Book of ASTM Standards, Part 6.

PROPOSED METHOD TO BE PUBLISHED AS INFORMATION

The committee recommends that the Proposed Methods of Test for Dielectric Constant and Dissipation Factor of Aviation Fuels be published as information as appended hereto.[2]

NEW TENTATIVE

Committee D-9 recommends that the Method of Test for Water in Insulating Oils by Extraction be accepted for publication as tentative as appended hereto.[3] The method is designed to measure the amount of water contained in transformer oil or other high-boiling point oils.

REVISION OF TENTATIVES

The committee recommends that the following tentatives be revised as indicated and continued as tentative:

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13-18, 1954.

[1] These tentatives now appear in the 1954 Supplement to Book of ASTM Standards, Part 6.

[2] This method appears in the February, 1955, Compilation of ASTM Standards on Electrical Insulating Materials.

[3] The new tentative was accepted by the Society and appears in the 1954 Supplement to Book of ASTM Standards, Part 6.

Tentative Method of Test for Molded Materials Used for Electrical Insulation (**D 48 – 52 T**):[5]

Section 17 (*a*).—Change the description of the test specimen to provide for use of flat washers in place of cupped washers. To accomplish this add the word "flat" before "washers" in the first sentence; also omit the second sentence which reads as follows: "The washers shall be slightly cupped with the concave side placed toward the specimen."

Figure 1.—In the notation at the top of this figure omit the word "cupped" in describing the brass washers used with the test specimen.

Tentative Method of Testing Electrical Insulating Oil (**D 117 – 53 T**):[4,6]

New Sections.—Add the following three new sections under the heading "Water in Insulating Oils":

56. *Definition.*—Water as determined in this test includes total water in the insulating oil. The unit of measure of the water is in parts per million (ppm).

57. *Significance.*—The test is significant in that it will show the presence of water which may not be evident from electrical tests.

58. *Procedure.*—Water shall be determined in accordance with the Tentative Method of Test for Water in Insulating Oils by Extraction (ASTM Designation: D 1315).[7]

Section 35.—In line 2, before "oil" add the word "insulating."

Section 36.—Change to read as follows:

36. This method serves as a measure of the total constituents present in insulating oils that react with potassium hydroxide under the conditions of the test. Such constituents may consist of compounds resulting from the oxidation of the oil, added compounds, or contaminants.

Tentative Methods of Test for Electrical Resistance of Insulating Materials (**D 257 – 52 T**):[5]—These methods have been extensively revised as appended hereto.[1]

Tentative Methods of Testing Varnished Cloths and Varnished Cloth Tapes Used for Electrical Insulation (**D 295 – 52 T**):[5]

New Sections.—Add the following two new sections under the heading "Volume Resistance":

76. *Definition.*—The volume resistance of varnished cloths and tapes is the ratio of the d-c voltage applied to the electrodes which are in contact with the test specimen to the portion of the current between them that is distributed through the volume of the specimen, as determined under the prescribed conditions.

77. *Significance.*—The volume resistance test on varnished cloths and tapes is a nondestructive test. This test is useful in quality control and to supplement the data derived from power factor measurements.

Tentative Methods of Test for Sludge Formation in Mineral Transformer Oil (**D 670 – 42 T**):[5]

The committee recommends that the Sludge Accumulation Test (Method A) comprising Sections 2 to 14 be published as a separate tentative method, revised as appended hereto.[1]

Tentative Specification for Phenolic Molding Compounds (**D 700 – 52 T**):[5]

Committee D-9 joins with Committee D-20 in recommending the following revision:

Table I.—In Footnote *a*, third line, following the word "determined," add the words "on a molded test specimen."

Tentative Specifications for Vulcanized Fibre Sheets, Rods, and Tubes Used for Electrical Insulation (**D 710 – 52 T**):[5]

Table III.—Replace the specified maximum water absorption for each thickness range by a maximum value for each industrial thickness as follows:

Maximum Water Absorption Sheets
(Bone Grade)

Nominal thickness, in.	Change in weight, per cent	
	2 hr	24 hr
1/32	55	63
1/16	30	55
1/8	20	48
3/16	17	42
1/4	14	37
5/16	12	33
3/8	11	30
7/16	11	27
1/2	10	25

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[4] See Editorial Note, p. 455.

[5] 1952 Book of ASTM Standards, Part 6.

[6] 1953 Supplement to Book of ASTM Standards, Part 6.

[7] 1954 Supplement to Book of ASTM Standards, Part 6.

Sheets (Commercial Grade and Electrical Insulation Grade)

Nominal thickness, in.	Change in weight, per cent 2 hr	24 hr
1/32	60	68
1/16	52	66
1/8	35	61
3/16	24	56
1/4	20	52
5/16	17	47
3/8	15	43
7/16	14	39
1/2	13	36
5/8	11	31
3/4	10	27
7/8	8	23
1	8	21
1 1/4	8	18
1 1/2	8	17
2	8	17

Appendix.—Add the following to Section A2, designating the present paragraph as A2(*a*):

(*b*) Typical values for modulus of elasticity in flexure for 1/4-in. vulcanized fibre are:

Direction	Modulus, psi
Machine Direction	1 000 000
Cross Direction	700 000

Tentative Recommended Practices for the Purchase of Uninhibited Mineral Oil for Use in Transformers and in Oil Circuit Breakers (**D 1040 – 49 T**):[5]

Table I.—Make the following addition to the screening specifications in Table I:

Property	Specified Value	ASTM Method
Interfacial Tension	[d]	D 971[c]

[c] Standard Method of Test for Interfacial Tension of Oil Against Water by the Ring Method (ASTM Designation: D 971).

[d] The normally expected range of interfacial tensions falls within the limits of 35 to 55 dynes per cm. A range may be established for oil from any industrial supplier.

Tentative Method of Test for Insulation Resistivity of Electrical Insulating Oils of Petroleum Origin (**D 1169 – 52 T**):[5]

New Appendix.—Add as Appendix I the present Appendix III entitled "Cells Used for Measuring Power Factor and Dielectric Constant of Insulating Liquids" of the Tentative Methods of Test for Power Factor and Dielectric Constant of Electrical Insulating Materials (D 150 – 47 T).

Tentative Specifications for Enclosures and Servicing Units for Tests Above and Below Room Temperature (**D 1197 – 52 T**):[5]

Table I.—Change the Time Constant, max, sec. for Grade A from "50" to "200," and for Grade B from "75" to "275."

Section 8(a).—After the third sentence add the following: "A recording instrument of equal deflection sensitivity may also be employed." In line 19, change "10 min." to "15 min."

Section 8(b).—Change the second sentence to read as follows:

> One junction shall be positioned within 2 in. of the locations of the specimen to be tested and the second placed successively at the approximate center of each cubic foot of available work space (except that for chambers containing less than 4 cu ft., the second junction shall be placed at the center of each 6-in. cube.

Section 8(e).—Change the first sentence to read as follows:

> Temperature drift shall be determined by means of the "standard specimen" or of an instrument of equal or greater thermal inertia, except that a device of lower thermal inertia may be used provided that the temperature is taken as being the mean of the highest and lowest temperatures observed over a 15-min. period.

Change the last sentence to read as follows:

> The temperature drift shall be the maximum deviation of any subsequent reading (or mean reading) from the original 2-hr. reading.

TENTATIVE REVISIONS OF STANDARDS

The committee recommends tentative revisions of the following standards as indicated. Additional tentative revisions of Methods D 348 and D 349 will be submitted to the Standards Committee.[4] These comprise changes in scope and addition of definitions and statements on significance of the various test procedures covered.

Standard Methods of Testing Sheet and Plate Materials Used for Electrical Insulation (D 229 – 49):[5]

Section 12.—Change Paragraph (*a*) to read as follows:

12. (*a*) For tests made in the flatwise direction on sheets 1 in. in thickness or over, the test specimen shall be in the form of a ½ by ½ by 1-in. right parallelepiped, with the 1-in. length being parallel to the thickness of the sheet; the ends of which are machined or ground flat and perpendicular to the 1-in. axis.

Add the following new Paragraph (*b*) and reletter the present Paragraph (*b*) as (*c*):

(*b*) For tests made in the edgewise direction on sheets ½ in. in thickness or over, the test specimen shall be in the form of a ½ by ½ by 1-in. right parallelepiped, with the 1-in. length being perpendicular to the thickness of the sheet; the ends of which are machined or ground flat and perpendicular to the 1-in. axis.

Section 13.—Change Paragraphs (*a*) and (*b*) to read as follows:

13. (*a*) For sheets ½ in. in thickness or over, five specimens shall be tested in the condition in which they are received with the load applied flatwise, five specimens with the load applied edgewise-lengthwise of the sheet, and five specimens with the load applied edgewise-crosswise of the sheet.

(*b*) For sheets less than ½ in. in thickness, five specimens shall be tested in the condition in which they are received with the load applied flatwise of the sheet.

Add the following new Paragraphs (*c*) and (*d*), and revise and reletter the present Paragraph (*c*) as (*e*):

(*c*) Specimens that break at some obvious fortuitous flaw shall be discarded and retests made, unless such flaws constitute a variable, the effect of which it is desired to study.

(*d*) Results (on specimens) that deviate markedly from the mean value of all tests shall be retained unless Paragraph (*c*) applies. In this case additional tests shall be run, the exact number to be fixed by the desired (statistical) significance level.

(*e*) The crosshead speed of the testing machine shall be 0.050 in. per min when the machine is running idle.

Section 2.—Change the definitions for "Lengthwise" and "Crosswise" to read as follows:

Lengthwise (*LW*).—In the direction of the sheet known to be stronger in flexure.

Crosswise (*CW*).—In the direction of the sheet known to be weaker in flexure and shall be 90 deg to the lengthwise direction.

Delete the Note at the end of this section.

Standard Methods of Testing Laminated Tubes Used for Electrical Insulation (D 348 – 52):[5]

Section 10.—Add the following new Paragraphs (*b*) and (*c*), and revise and reletter the present Paragraph (*b*) as (*d*):

(*b*) Specimens that break at some obvious fortuitous flaw shall be discarded and retests made, unless such flaws constitute a variable, the effect of which it is desired to study.

(*c*) Results (on specimens) that deviate markedly from the mean value of all tests shall be retained unless Paragraph (*b*) applies. In this case additional tests shall be run, the exact number to be fixed by the desired (statistical) significance level.

(*d*) The crosshead speed of the testing machine shall be 0.050 in. per min when the machine is running idle.

Standard Methods of Testing Laminated Round Rods Used for Electrical Insulation (D 349 – 52):[5]

Section 13.—Change Paragraphs (*a*) and (*b*) to read as follows:

13. (*a*) Samples shall be tested in the condition in which they are received. For rods ⅛ to 1 in. in diameter, the test specimen shall have a diameter equal to the diameter of the rod and length conforming to the following requirements:

Diameter, in.	Length, in.	Slenderness Ratio
⅛ to ¼	½	16 to 8
¼ to ½	1	16 to 8
½ to 1	2	16 to 8

(*b*) For rods over 1 in. in diameter, specimens shall be standard ½ by ½ by 1-in. right parallelepipeds cut from the rods so as to be repre-

sentative of its cross-section both at the center and near the edges.

Section 14.—Add two new Paragraphs (*b*) and (*c*) and revise the present Paragraph (*b*) (new Paragraph (*d*)) to read as follows:

(*b*) Specimens that break at some obvious fortuitous flaw shall be discarded and retests made, unless such flaws constitute a variable, the effect of which it is desired to study.

(*c*) Results (on specimens) that deviate markedly from the mean value of all tests shall be retained, unless Paragraph (*b*) applies. In this case additional tests shall be run, the exact number to be fixed by the desired (statistical) significance level.

(*d*) The crosshead speed of the testing machine shall be 0.050 in. per min when the machine is running idle.

Standard Methods of Test for Power Factor and Dielectric Constant of Electrical Insulating Oils of Petroleum Origin (**D 924 – 49**):[5]

New Appendix.—Add as Appendix I the present Appendix III entitled "Cells Used for Measuring Power Factor and Dielectric Constant of Insulating Liquids" of the Tentative Methods of Test for Power Factor and Dielectric Constant of Electrical Insulating Materials (D 150 – 47 T).

ADOPTION OF TENTATIVES AS STANDARD

The committee recommends that the following three tentatives be approved for reference to letter ballot of the Society for adoption as standard:

Tentative Specifications for:

Natural Block Mica and Mica Films Suitable for Use in Mica-Dielectric Capacitors (**D 748 – 52 T**),[4,5]

Orange Shellac and Other Indian Lacs for Electrical Insulation (**D 784 – 52 T**).[5]

Tentative Methods of Test for:

Sludge Formation in Mineral Transformer Oil (**D 670 – 42 T**).[5] The committee recommends the High-Pressure Oxidation Test (Method B) for adoption as standard, revised as appended hereto,[8] Method A being continued as tentative in revised form as indicated above.

ADOPTION OF TENTATIVE REVISIONS AS STANDARD

The committee recommends that the tentative revisions[1] of the Standard Method of Test for Power Factor and Dielectric Constant of Natural Mica (**D 1082 – 51**),[5] comprising new Sections 2 and 8, be approved for reference to letter ballot of the Society for adoption as standard.

REVISION OF STANDARD, IMMEDIATE ADOPTION

The committee recommends, jointly with Committee D-20, that the following revision of the Standard Methods of Conditioning Plastics and Electrical Insulating Materials for Testing (**D 618 – 53**)[5] be approved for reference to letter ballot of the Society and requests the nine-tenths affirmative vote for immediate adoption:

Section 4.—In Paragraph (*b*), line 8, delete the words "(or other suitable desiccant)."

Add to Note 3 the following sentence: "Other enclosures, desiccants, or desiccating techniques may be used which produce and maintain an atmosphere equivalent to that over anhydrous calcium chloride."

In Paragraph (*c*), which covers Procedure C for conditioning prior to test, add the following new Note 5, renumbering the subsequent notes accordingly:

NOTE 5.—It has been found that, for certain tests and materials, more reliable data are obtained in enclosures with circulating air rather than still air. In such cases enclosures with circulating air should be used.

In Paragraph (*f*), which describes Procedure F for conditioning prior to test, add as a new Note 9 the same note as Note 5 given above.

REVISION OF STANDARD AND REVERSION TO TENTATIVE

The committee joins with Committee D-20 in recommending that the Standard Method of Test for Water Absorption of

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[8] The new standard was accepted by the Society and appears in the 1954 Supplement to Book of ASTM Standards, Part 6.

Plastics (D 570 – 42)[5] be revised as follows and reverted to tentative:

Section 4.—Delete the words "weighed individually and then."

Change the last word in Paragraph (*a*) from "reweighed" to "weighed."

Section 7.—Change Item (*2*) to read: "The conditioning time and temperature."

TENTATIVES CONTINUED WITHOUT REVISION

The committee recommends that the following tentatives be continued without change for an additional year while work is in progress:

Tentative Methods of Test for:

Saponification Number of Petroleum Products by Color-Indicator Titration (D 94 – 52 T),

Varnishes Used for Electrical Insulation (D 115 – 52a T),

Varnished Cloths and Varnished Cloth Tapes Used for Electrical Insulation (D 295 – 52 T), and

High-Voltage Low-Current Arc Resistance of Solid Electrical Insulating Materials (D 495 – 48 T).

Tentative Specifications for:

Black Bias-Cut Varnished Cloth and Varnished Cloth Tape Used for Electrical Insulation (D 373 – 51 T), and

Absorbent Laminating Paper for Electrical Insulation (D 1080 – 52 T).[4]

CONTINUATION OF TENTATIVE REVISIONS

The committee recommends that the tentative revision of the Standard Method of Testing Flexible Varnished Tubing Used for Electrical Insulation (D 350 – 48), and the Standard Methods of Test for Dielectric Strength of Electrical Insulating Materials at Commercial Power Frequencies (D 149 – 44) be continued for an additional year while work on the methods is in progress.

CHANGE IN JURISDICTION

The committee recommends that the Recommended Practices for Maintaining Constant Relative Humidity by Means of Aqueous Solutions (**D 1041 – 51**)[5] be transferred from the joint jurisdiction of Committee D-9 and Committee D-20 on Plastics to the jurisdiction of Committee E-1, since the recommended practice is of a general nature. The standard will be given an "E" designation.

The recommendations appearing in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[9]

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Insulating Varnishes, Paints, and Lacquers (A. H. Haroldson, chairman) has prepared proposed Tentative Methods of Test for Silicone Insulating Varnish,[4] and has recommended the adoption as standard of Tentative Specifications D 784.

The name of Section G was changed from "Heat Endurance" to "High-Temperature Properties and Thermal Stability."

Section C on Laminating Varnishes (A. H. Haroldson, chairman).—Round-robin tests using the constant temperature wax bath developed by E. R. Andrews were conducted by two laboratories. Good agreement was obtained with the tests conducted at 170 C. The results indicate that a temperature of 165 or 170 C should be used for the determination of set time of phenol-formaldehyde laminating varnishes. On the basis of these results it was decided to conduct another round-robin test program which was started in January, 1954, with six members participating.

Section D on Silicone Varnishes (J. S. Hurley, chairman).—Considerable time was devoted to studying the round-robin test results on the effect of elevated temperatures on the dielectric strength of silicone varnish impregnated heat-cleaned glass cloth tape. The work on this problem has not been completed.

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[9] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

A comparison of the dielectric strength data submitted by five laboratories participating in the round-robin test program indicated the necessity for further study.

A task force was appointed to recheck the method of drainage using a definite thickness foil.

Section G on High-Temperature Properties and Thermal Stability (H. K. Graves, chairman).—A number of members expressed interest in active participation in the new work that is planned for Section G to study new methods for evaluating the effect of elevated temperatures on the electrical and physical properties of varnish films. Section G will cooperate with other sections on problems pertaining to high-temperature properties and thermal stability.

Section J on Physical Properties (K. N. Mathes, chairman) has sent out a questionnaire to obtain information and classify the methods which are being used in the industry for the determination of viscosity of electrical insulating varnishes.

A program has been planned, in cooperation with Sections A and B, to classify electrical insulating varnishes according to uses and applications. Use statements have been prepared on alcohol soluble varnishes and oxidizing air-drying varnishes.

Section K on Definition and Significance of Tests (R. W. Nye, chairman) prepared the recommendation that the scope of the types of varnishes for which tests are available be enumerated in the first paragraph of the Methods of Testing Varnishes Used for Electrical Insulation (D 115 - 52*a* T) and that no attempt be made to formulate fundamental definitions of what constitutes electrical insulating varnishes. It was suggested that footnotes be used to cover other types of varnishes that might be considered to fall under this general type of varnishes.

Subcommittee III on Plates, Rods, Tubes and Molded Material (E. A. Russell, chairman).—Work is under way on the preparation of specifications for high-temperature tubing based on round-robin tests on the heat aging of plastic tubing at 130 C.

Significance statements were prepared for Methods D 348 and D 349. A revision of Specifications D 700 on Molding Compounds is being prepared to include new types comprising rubber-modified phenolic molding compounds.

Consideration is being given to the possibility of the use of roller electrodes for dielectric strength testing of entire areas of sheet materials. A proposed procedure for cleaning specimens for insulation resistance testing was submitted to letter ballot of the subcommittee and referred to Subcommittee XII.

Section Q on Mechanical Properties (P. Brown, chairman) is being discontinued and Committee D-20 will have sole jurisdiction over mechanical testing procedures. Committee D-9, through Subcommittee III, will be represented on the D-20 subcommittees involved.

Two new sections have been created: Section X on Polyester Glass Molded and Laminated Materials, and Section Y on Heat Stability and Heat Resistance.

Subcommittee IV on Liquid Insulation, (F. M. Clark, chairman) has continued its various studies on the testing of liquid insulating materials during the past year. More than ten years ago a cooperative program of testing three grades of mineral insulating oil and coordinating the performance of these oils in actual service was undertaken. These transformers are now being terminated and the final reports on the apparatus and oils which were in this service will be available this coming year. Other transformers containing reclaimed oil are continuing under observation with periodic testing of samples drawn from the apparatus.

The examination of several proposed test procedures for evaluating the sludge forming properties of both straight and inhibited mineral insulating oils is being continued, and a further study is now under way to evaluate the use of soluble metal catalysts as oxidizing media. This latter work embraces the European technique suggested by Technical Committee 10 of the International Electrotechnical Commission, of which the chairman of Subcommittee IV is a member.

The Tentative Methods of Test for Sludge Formation in Mineral Transformer Oil (D 670 - 42 T) have now been separated into two methods, each with its own number, with the high-pressure bomb test (Method B) adopted as a standard method, and the sludge accumulation test (Method A) continued as tentative.

The Method of Test for Water in Insulating Oil by the Extraction Method has been prepared by Subcommittee IV. Work is being continued on the standardization of a second method using the Karl Fisher reagent and electrometric titration.

The subcommittee's active section groups have been increased to twenty-one by the formation of Section K to study viscosity measurements of transformer and switch oils at low temperatures, and Section P to study the determination of peroxides in insulating oils. In addition, Section J on Gas Content has been reactivated to study the application of this test procedure to cable oils at the request of Section F, which is continuing its work on the development and application of tests for cable oil evaluation.

Statements on significance and definition of tests on askarels have been approved and have been added to the Tentative Methods of Testing Askarels (D 901 - 53 T). This revised standard has been recommended for approval as American Standard. Tentative Methods of Testing Electrical Insulating Oils (D 117 - 53 T) have been revised and recommended for approval as American Standard.[4]

Other recommended changes in existing methods being offered for letter ballot approval are the Tentative Recommended Practice for the Purchase of Uninhibited Mineral Oil for Use in Transformers, and in Oil Circuit Breakers (D 1040 - 49 T) to include a reference to interfacial tension, and additions to the Standard Method of Test for Power Factor and Dielectric Constant of Electrical Insulating Oils of Petroleum Origin (D 924 - 49). A new Tentative Method of Test for Corrosive Sulfur in Electrical Insulating Oils (D 1275 - 53 T) was issued last year.

Section activities continuing will deal with methods for determining metals in oil, sampling, steam emulsion number, transformer oil additives, dielectric strength, and interfacial tension.

No symposium on insulating oil was planned for the past year, but technical papers on inhibitor additives by eminent foreign technical representatives are anticipated for the fall meeting.

Subcommittee VI on Solid Filling and Treating Compounds (W. R. Dohan, chairman).—The Tentative Methods of Testing Hydrocarbon Waxes Used for Electrical Insulation (D 1168 - 51 T) were revised[1] during the year to include an alternative method of measuring viscosity, and several notes were added to assist in the use of the various tests.

A second draft of proposed revisions of the Standard Methods of Testing Solid Filling and Treating Compounds

(D 176 – 44) was acceptable in part, but the electrical test methods did not meet the subcommittee's approval. The electrical tests, while satisfactory for asphaltic compounds for which the methods were originally intended, will not give reliable results with waxes or similar materials with relatively high solidification shrinkage. Section A will undertake alternative methods for such materials.

Section E on Scope and Significance (R. H. Titley, chairman) conducted a survey of consumer interpretation of the significance of tests in Methods D 176, but a poor response was obtained. A survey of the methods in actual use by members of Subcommittee VI showed that physical tests were widely used but electrical tests were in active use in only a few companies.

Section F on Polymerizable Embedding Materials (H. K. Graves, chairman) has made further progress in the preparation of methods of test for these materials. It is anticipated that the materials will eventually supersede the more conventional types in a great number of applications.

Sections B and C on Chemical and Physical Properties of Waxes were discharged since a subcommittee of Committee D-2 on Petroleum Products and Lubricants is actively working in this field.

Subcommittee VII on Insulating Fabrics (H. K. Graves, chairman) has under way a major revision of the Tentative Methods of Testing Varnished Cloth and Varnished Cloth Tapes for Electrical Insulation (D 295 – 52 T). Negative ballots in the responsible section have been reconciled and it is expected that the rewrite will be ready shortly for subcommittee letter ballot. The method will contain definition and significance statements.

Revisions of the Standard Methods of Testing Flexible Varnished Tubing (D 350 – 48) and the Tentative Specification for Flexible Treated Cotton and Rayon Sleeving (D 372 – 47 T) have been completed. Work will be started shortly on methods for silicone rubber glass fiber sleeving.

A draft of specifications for varnished glass fabrics and tapes has been written but has not as yet received Section D approval. Work is under way on methods for silicone rubber glass fabrics and on "Teflon" glass fabric.

A complete revision of the Tentative Methods of Testing Pressure-Sensitive Adhesive Tapes (D 1000 – 48 T) is under way, and it is expected that the revision will contain definitions and significance statements as well as methods for "elastoplastic" pressure-sensitive tapes. Thermosetting electrical adhesive tapes are also being considered and methods will be worked on soon.

A new Section F on Heat Stability has been formed and has completed a paper based on the section's work for presentation at the June symposium being sponsored by section K of Subcommittee XII. A program of immediate work for the section has been agreed upon and the program will get under way immediately in view of the wide interest in heat stability of insulating materials.

The subcommittee has reviewed seven NEMA specifications on varnished fabrics and has started work to prepare ASTM standards for these materials where such do not exist.

Subcommittee VIII on Insulating Papers (H. A. Anderson, chairman).—The major accomplishment was the completion of the Tentative Specifications for Electrical Insulating Paper—Interlayer Type (D 1305 – 54 T).[1] The standard covering untreated paper for use in coils and transformers represents the second of the three contemplated insulating paper specifications, with that on Absorbent Paper for Laminates (D 1080 – 52 T)[4] now in use, and one on capacitor tissue in preparation.

Section A on Chemical Tests (J. I. Adams, chairman) is cooperating with the Joint D6-D9 Committee on Paper in reviewing the Methods D 202 for determination of pH of unbuffered papers and analytical methods for water soluble chlorides. Evidence to date indicates variable test results may be due to failure to observe specified details of the pH analysis, including controlled nitrogen bubbling time. Cooperative work is also in progress on air resistance methods to supplement the coverage for relatively open papers now provided by Method D 726. A draft of proposed methods for porosity of medium and tight sheets has been circulated to the subcommittee for comments.

Section B on Physical Tests (E. G. Ham, chairman) has already begun work on revision of Methods D 202 – 53 T to include methods for measurement of surface friction (paper to paper) and wet tensile strength (using the Finch stirrup). Surface friction is of importance in cable core wrap papers and wet tensile strength is necessary in absorbent paper which is impregnated in the manufacture of phenolic laminates for electrical insulation.

Section C on Mechanical Strength (P. F. Wehmer, chairman) has prepared a draft of test methods for measuring the elongation of creped papers. Agreement between various laboratories is presently rather poor, due chiefly to changes in the amount of unfolding which takes place in mounting the creped paper in the jaws of the testing machine. A frame of pressure-sensitive tape on the test specimens is under consideration and the section is also considering the merits of floating the creped paper on the surface of water (as used in specifying creped paper for making cigarette filters).

Section F on Specifications for Insulating Paper (H. A. Anderson, chairman) has circulated proposed revisions in wet tensile strength and air-resistance values now appearing in Specifications D 1080 – 52 T on Absorbent Paper[4] in order to ease slightly those requirements which paper mills are presently having difficulty in meeting consistently. A new draft of a specification on Kraft capacitor tissue type of insulating paper has also been circulated in the subcommittee. This draft includes dielectric strength and conducting path limits, but it has been decided not to attempt to include accelerated life requirements on capacitor units (as a test of the paper) pending standardization and increased availability of accelerated life test equipment. At one of its meetings, the section witnessed a demonstration of a new conducting path test set which automatically counts and marks the location of conducting particles.

Subcommittee IX on Mica Products (K. G. Coutlee, chairman).—Definite progress is being made in the development of physical standards of natural mica which will serve to illustrate the eleven quality levels of Specifications D 351. A single composite sample finally has been agreed upon which will be suitable for classifying mica regardless of source or basic color. The standard will be cut to the largest usable rectangle by which physical quality is judged and mounted between clear plastic sheets for protection during use.

Specification D 748 – 52 T was revised last year to bring it up to date and include certain technical improvements and is now being recommended for adoption as standard.[4]

The proposed revision of Methods D 352 on Pasted Mica is under way and a considerable amount of activity and interest in this project is being shown by members of Section B.

Section D on Significance (C. L. Craig, chairman) is preparing significance statements for the various mica specifications and test methods.

A new Section E on High-Temperature Properties has been organized and plans to start work in the near future.

Subcommittee XII on Electrical Tests (G. M. L. Sommerman, chairman) prepared the revision of Tentative Method D 150, which has been accepted by the Administrative Committee on Standards. It also prepared the Method for Measurements of Dielectric Constant and Dissipation Factor of Aviation Fuels, which is recommended for publication as information,[2] as well as the revision of Tentative Method D 257.

Section A on Resistivity (A. H. Scott, chairman) and Section C on Dielectric Loss (R. F. Field, chairman) have been active in preparing the revisions to Methods D 257 and D 150, respectively.

Section E on Dielectric Strength (R. W. Chadbourn, chairman) has prepared revisions of Method D 149 - 44 and a proposed new Tentative Method for Dielectric Proof Voltage Testing of Thin Solid Electrical Insulating Materials which will be submitted to letter ballot.

Section G on Arc Resistance (Thomas Hazen, chairman) is studying revisions of Method D 495 - 48 T. This section plans to hold a special one-day meeting on power-arc resistance.

Section H on Electrodes (K. G. Coutlee, chairman) completed the preparation of a proposed new method on aviation fuels. This section is studying the problem of specifying electrodes for electrical tests on thin films.

Section K on High-Temperature Performance (K. N. Mathes, chairman) has arranged for a Symposium on Temperature Stability of Electrical Insulating Materials[10] at the Annual Meeting in June. A number of subcommittees have set up sections on high-temperature performance of their materials. Mr. Mathes reported that, at a meeting of Subcommittee 2C on Classification of Insulating Materials IEC-TC-2 on Rotating Machinery in London, it was agreed that temperature classification will be described by general definition rather than by lists of materials. This will be discussed further at the IEC meeting in Philadelphia in September, 1954.

A proposal to start work on corona testing of materials, including the resistance of materials to corona or ionization, was favorably received. A group under the interim leadership of E. B. Curdts will explore this activity, including scope and significance of tests, and will report at the next meeting.

Subcommittee XIV on Conditioning (A. C. Webber, chairman) has continued active work on the methods under its jurisdiction. The general conditioning method (D 618) has been revised twice to improve its usefulness and increase its specificity. The Specifications for Enclosures and Servicing Unit for Tests Above and Below Room Temperature (D 1197 - 52 T) have been studied intensely by the section and equipment manufacturers. This work has led to two revisions and further work is in progress. The Standard Methods of Maintaining Relative Humidity by Measurement of Aqueous Solutions (D 1041 - 51) is of sufficient general interest to the Society that it has been transferred to the jurisdiction of Committee E-1 on Methods of Testing for publication as an "E" standard.

Work is continuing on the important problem of measurement of humidity in small enclosures.

Subcommittee on Symposium (L. B. Schofield, chairman).—No symposia were held during the meetings at Atlantic City, N. J., or Roanoke, Va. However, work has been in progress in setting up the symposium for the June meeting in Chicago, Ill., on the subject of Temperature Stability of Electrical Insulating Materials. K. N. Mathes, chairman of Section K of Subcommittee XII, has had the chief responsibility in formulating this program.[10]

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[10] Issued as separate publication *ASTM STP No. 161.*

During the past year another Symposium on Insulating Oil sponsored by Subcommittee IV has been outlined. This symposium is planned for the fall of 1954.

This report has been submitted to letter ballot of the committee, which consists of 177 members; 112 members returned their ballots, of whom 79 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

A. H. SCOTT,
Chairman.

B. E. ELY,
Recording Secretary.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee D-9 presented to the Society through the Administrative Committee on Standards the following recommendations:

Tentative Methods of Test for:
- Silicone Insulating Varnishes (D 1346 – 54 T).

Revision of Tentative Methods of Testing:
- Electrical Insulating Oils (D 117 – 53 T).

Revision and Reversion to Tentative of Standard Specification for:
- Natural Block Mica and Mica Films Suitable for Use in Fixed Mica-Dielectric Capacitors (D 748 – 54).

These recommendations were accepted by the Standards Committee on September 28, 1954; the new Methods D 1346 and the revised Specification D 748 appear in the 1954 Supplement to Book of ASTM Standards, Part 6, and the revised Methods D 117 appear in Parts 5 and 6 of the 1954 Supplement.

On December 22, 1954, the Administrative Committee on Standards accepted the following recommendations submitted by Committee D-9:

Revision of Tentative Specifications for:
- Non-Rigid Polyvinyl Tubing (D 922 – 52 T), and
- Absorbent Laminating Paper for Electrical Insulation (D 1080 – 52 T).

Revision of Tentative Method of:
- Testing Vulcanized Fiber Used for Electrical Insulation (D 619 – 52 T),
- Testing Non-Rigid Polyvinyl Tubing (D 876 – 52 T), and
- Test for Silicone Insulating Varnishes (D 1346 – 54 T).

Tentative Revision of Standard Methods of:
- Testing Laminated Tubes Used for Electrical Insulation (D 348 – 52),
- Testing Laminated Round Rods Used for Electrical Insulation (D 349 – 52), and
- Sampling Electrical Insulating Oil (D 923 – 49).

The revised tentatives and tentative revisions of standards appear in the 1954 Supplement to Book of ASTM Standards, Part 6, and in the February, 1955, Compilation of ASTM Standards on Electrical Insulating Materials.

APPENDIX

ERRORS OCCURRING IN THE MEASUREMENT OF DIELECTRIC CONSTANT

BY ROBERT F. FIELD[1]

The dielectric constant of an insulating material is the ratio of the parallel capacitance, C_p, of a given configuration of electrodes with the material as the dielectric, to the capacitance, C_v, of the same electrode configuration with a vacuum as the dielectric.

$$K = C_p/C_v \ldots\ldots\ldots\ldots (1)$$

Implicit in this definition is the condition that the material must extend to infinity in all directions.

GUARD-ELECTRODE SYSTEM

In any attempt to determine the dielectric constant of a material by measuring these two capacitances, several kinds of errors can occur. Obviously the material cannot extend to infinity, and the electrodes must be supported by a rigid insulating material, which itself contributes a capacitance. These difficulties are approximately overcome by the use of a guard electrode and a complete guard shield, shown schematically in Fig. 1 for parallel circular electrodes. Guard electrodes can equally well be applied to cylindrical electrodes. Moon and Sparks (**1**)[2] have shown that, when the width, *c*, of the guard electrode is greater than 2.5 times the spacing, *t*, of the electrodes, the capacitance between the measuring electrodes is within 0.01 per cent of that which would hold if the guard electrodes extended to infinity. When *c* is only twice *t*, the error increases to −0.2 per cent, and to −0.8 per cent for *c*/*t* equal to 1.5. However, since this error is essentially independent of the dielectric constant of the medium, the error in dielectric constant, as calculated from Eq 1, will be vanishingly small.

When liquids are measured, it is generally unnecessary to evacuate the cell, since the dielectric constant of air is known to better than 0.001 per cent (**2–6**). The dielectric constant of dry air at 23 C and 760 mm Hg pressure is 1.000530. At other Centigrade temperatures, *T*, and Hg pressures, *P*, and for different fractional relative humidities, *H*, within the temperature range 10 to 27 C, its divergence from unity is:

$$K - 1 = 0.00053 \frac{296}{273 + T} \frac{P}{760} + 0.00025\, H \ldots (2)$$

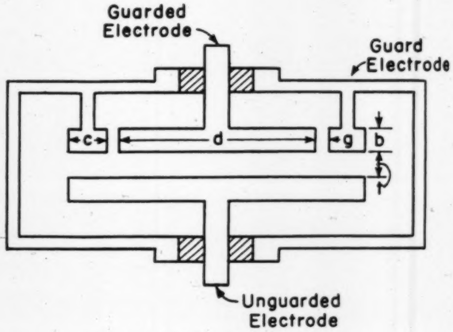

FIG. 1.—Three-Terminal Cell.

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[1] Watertown, Mass.; formerly with General Radio Co., Cambridge, Mass.

[2] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 478.

An alternative to measuring the capacitance between the measuring electrodes consists in calculating their direct interelectrode vacuum capacitance, C_v, which for a circular electrode of diameter, d, is:

$$C_v = 0.06954 \frac{d^2}{t} \mu\mu\text{f(cm)} = 0.17663 \frac{d^2}{t} \mu\mu\text{f(in.)} \dots (3)$$

Considering the case where the guarded and guard electrodes are at the same potential, so that the lines of force between them and the unguarded electrode are essentially parallel, it is obvious that the effective diameter, d, of the guarded electrode must be increased by the gap width, g, when this gap is negligible compared with the electrode spacing, t.

TABLE I.—FRINGING CONSTANTS AND CAPACITANCE ERRORS.

t, in.	g/t	δ/t	δ, in.	$4\delta/d$, per cent	δ/d, per cent	$0.0002/t$, per cent	Sum, per cent
1	2	3	4	5	6	7	8
0.0625	0.32	0.02004	0.00125	0.250	0.062	0.32	0.58
0.125	0.16	0.00501	0.00050	0.100	0.025	0.16	0.38
0.1875	0.107	0.00223	0.00042	0.084	0.021	0.11	0.33
0.25	0.08	0.00125	0.00031	0.062	0.015	0.08	0.30

When, however, the ratio, g/t, of gap width to electrode spacing is appreciable, the increase in the radius of a circular electrode or in the half length of a cylindrical electrode is less than half the gap width by a fringing constant, δ, which is a function of this ratio. For very thick electrodes, such as are shown in Fig. 1:

$$\frac{\delta}{t} = 0.080 \left(\frac{g}{t}\right)^2 \text{for } \frac{g}{t} < 1.0, \quad \text{or } \frac{\delta}{g} = 0.080 \frac{g}{t} \dots (4)$$

The more complex formulas, from which this expression is derived, were developed by Rosa and Dorsey (7) and Snow (1) for guarded air capacitors. They will also apply for the case of a liquid having a dielectric constant greater than unity. No formula is available for the case where a solid is placed between the electrodes, so that there is a discontinuity in dielectric constant in the gap between guarded and guard electrodes. Under such conditions the fringing constant, δ, will be somewhat decreased.

For very thin electrodes, such as are usually applied to solids:

$$\left.\begin{aligned} \frac{\delta}{t} &= \frac{2}{\pi} \ln \cosh \frac{\pi g}{4t} = 1.466 \log \cosh 0.7858 \frac{g}{t} \\ &= 0.196 \left(\frac{g}{t}\right)^2 \text{for } \frac{g}{t} < 0.25, \text{or } \frac{\delta}{g} = 0.196 \frac{g}{t} \end{aligned}\right\} \dots (5)$$

This formula was developed by Amey (8) for the measurement of the d-c conductivity of solids. This is equivalent for capacitance measurements to assuming a zero dielectric constant in the gap and results in a maximum value of the fringing constant, δ. No formula is available for the actual condition of a vacuum or air in the gap space, for which the fringing constant will be somewhat decreased.

In the range where $g/t < 0.25$, the ratio of the fringing constants determined by Eqs 5 and 4 is 2.46, and no method has been developed for finding the value of δ for intermediate electrode thicknesses. There is then a considerable uncertainty in determining the fringing constant, even for the case of thin electrodes. The error must be considered to be at least $\delta/4$. Values of δ for 2-in. diam electrodes for a gap width of 0.02 in., which is about the least than can be obtained with thin electrodes, are given in Table I for various spacings, t.

The error produced in the calculated value of capacitance C_v, if the correction is not applied, is given as $4\delta/d$ in column 5 of Table I, whereas column 6 shows the estimated error δ/d with the correction applied. For thick electrodes Moon and Sparks (1) have shown how the gap can be reduced to 0.001 in., thus reducing these errors by a factor of 400 to negligibility.

The errors occurring in the measurement of diameter, d, and thickness, t, are usually dominant when the gap-width correction has been applied. If the thickness can be measured to 0.0002 in., the resulting error is as given in column 7 of Table I. If a 2-in. diam guarded electrode can be measured as to diameter to 0.002 in., the error in the area is 0.2 per cent. The sum of these three errors is given in the last column of Table I. Since capacitance at the level of 20 $\mu\mu$f can be measured to an accuracy between 0.1 and 0.2 per cent, the over-all error in the determination of the dielectric constant of a solid by this method is between 0.4 and 0.8 per cent, depending on the thickness of the specimen.

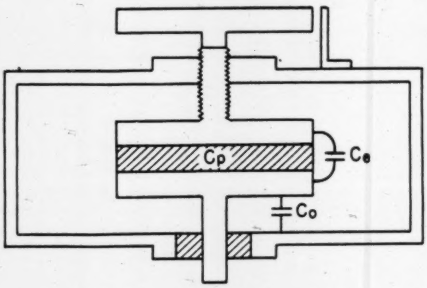

FIG. 2.—Micrometer-Electrode System.

It will be well at this place to point out that theoretically the guarded and guard electrodes need not be at the same potential, since direct interelectrode capacitances depend only on the geometry of the electrodes and not on their potential differences. Actually, however, the possibility of a voltage coefficient of capacitance in the dielectric under measurement and of sparking across the gap under a high voltage makes it desirable to bring the guarded and guard electrodes to the same potential.

MICROMETER-ELECTRODE SYSTEM

A second method of meeting the conditions implicit in Eq 1 for solid dielectrics is the use of the micrometer-electrode system originally devised by Hartshorn (9) to eliminate the error caused by series inductance at high frequencies. Its method of operation is shown schematically in Fig. 2. The electrical system is first calibrated for capacitance in terms of the spacing of the electrodes as measured by the setting of a micrometer screw. Since a difference in capacitance for two positions of the screw is always involved, the calibration can be based on any convenient reference position and need not include the entire capacitance, C_0, to the case. The dielectric specimen, which usually has the same diameter as the micrometer electrodes, is clamped tightly between the electrodes. The total capacitance, C', of the system is made up of the capacitance, C_p, of the specimen, the capacitance, C_0, of the insulated electrode to the case or to some part thereof, and the edge capacitance C_{ep}, between the electrodes.

$$C' = C_p + C_0 + C_{ep} \qquad (6)$$

The specimen is removed and the grounded electrode is screwed down until the total capacitance, C', is the same as before. This is the calibration capacitance of the electrode system at this spacing. Let C_t be the calibration capacitance of the system at the spacing, t, equal to the thickness of the specimen, C_{at} the direct interelectrode air capacitance of the specimen, and C_{et} the edge capacitance at spacing t.

$$C_t = C_{at} + C_0 + C_{et} \qquad (7)$$

Combining Eqs 6 and 7, the parallel capacitance of the specimen is:

$$C_p = C' - C_t + C_{at} \qquad (8)$$

provided that the edge capacitances, C_{ep} and C_{et}, are the same.

Both because the capacitance of a parallel plate capacitor varies inversely with the separation of the electrodes, and hence cannot be made direct-reading in capacitance, and because the construction of a micrometer-electrode system is usually not made so precisely as that of a worm-driven multiple-plate capacitor, the accuracy of a capacitance measurement at the level of 20 $\mu\mu$f is only about 0.5 per cent. It is then more accurate and usually more convenient at audio frequencies, where the existence of series inductance is unimportant, to use the micrometer-electrode system merely as a transfer system and to measure capacitance on the same standard capacitor as would be used for guard-electrode measurements. This capacitor is connected in parallel with the micrometer-electrode system, giving a total capacitance, C'', when its own capacitance is C_N and the specimen is clamped between the electrodes.

$$C'' = C_N + C_p + C_0 + C_{ep} \ldots\ldots (9)$$

The specimen is removed, the grounded electrode is set at a spacing, t, equal to the thickness of the specimen, and the standard capacitor is increased to a capacitance C_{Nt}' such that the total capacitance is the same as before.

$$C'' = C_{Nt}' + C_{at} + C_0 + C_{et} \ldots (10)$$

Combining Eqs 9 and 10, the parallel capacitance of the specimen is:

$$C_p = C_{Nt}' - C_N + C_{at} \ldots\ldots\ldots (11)$$

provided that the edge capacitances, C_{ep} and C_{et}, are the same.

The edge capacitance, C_{ep}, with the specimen in place will differ from the value C_{et} with the specimen removed. The observations of Moon and Sparks (1) referred to above indicate that the electric field between parallel electrodes is not uniform but decreases as the edge is approached. Let the resulting capacitance be less than that calculated as C_{at} from Eq 3 by a quantity C_f. Then the capacitance C_p contributed by the specimen will be less by KC_f. The second parts of Eqs 8 and 11 are then increased by the term $(K - 1)\ C_f - (C_{ep} - C_{et})$. It appears to be very difficult to determine the magnitude of this term or of either of its components. Some unsatisfactory evidence to be described later in this paper indicates that it can cause a maximum error of about +1 per cent. Each component, and hence their difference, is decreased when the diameter of the specimen is made smaller than that of the electrodes. Moon and Sparks (1) indicate that each component will become negligible when the electrodes extend beyond the specimen by 2.5 times the thickness of the specimen. Powell[3] finds that the error will be negligible when this extension of the electrodes equals the specimen thickness. Baker (10) arrives at the same conclusion, and further evidence will be given later in this paper. Even so, more observations should be obtained.

Even though the dielectric specimen is smaller than the electrodes, Eqs 8 and 11 still hold. Let C_t' be the direct air capacitance of the electrodes at the spacing, t, equal to the thickness of the specimen. Equation 6 becomes:

$$C' = C_p + C_t' - C_{at} + C_0 + C_{ep} \ldots (12)$$

where $C_t' - C_{at}$ is the direct air capacitance surrounding the specimen. Equation 7 becomes:

$$C_t = C_t' + C_0 + C_{et} \ldots\ldots (13)$$

Combining Eqs 12 and 13:

$$C_p = C' - C_t + C_{at} \ldots\ldots\ldots (8)$$

and similarly for Eq 11.

In the development of Eqs 8 and 11 it has been assumed that the surfaces of the electrodes and of the specimen are so nearly plane and parallel that there is no series air capacitance between the electrodes and specimen. This is by no means the case, as data given later in this paper will show. It is always necessary to apply thin electrodes to the specimen, either foil or finely divided metal, in order to eliminate this series capacitance. The spacing, r, of the micrometer electrodes with the specimen clamped between them will be greater than the thickness, t, of the specimen by the thickness of these thin electrodes and also by any irregularities of the specimen itself.

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[3] R. C. Powell, Report to Meeting of Section C on Dielectric Loss Characteristics of Subcommittee XII on Electrical Tests of ASTM Committee D-9 on Electrical Insulating Materials, October 29, 1952.

As long as the specimen is the same size as the micrometer electrodes, Eqs 8 and 11 still hold, since the edge capacitance, C_{et}, can change only by a negligible amount between the spacing, t, and the greater spacing, r. However, for a specimen smaller than the electrodes, this increased spacing, r, must be used, because it defines the direct air capacitance surrounding the specimen. Let C_r' be the direct air capacitance of the electrodes at their spacing, r, when the specimen is clamped between the electrodes, and C_{ar} be the direct air capacitance of the specimen if its thickness were r. Equation 12 becomes:

$$C' = C_p + C_r' - C_{ar} + C_0 + C_{ep} \quad \dots (14)$$

where $C_r' - C_{ar}$ is the direct air capacitance surrounding the specimen. Let C_r be the calibration capacitance of the system at the spacing r. Then Eq 13 becomes:

$$C_r = C_r' + C_0 + C_{er} \quad \dots\dots\dots (15)$$

Combining Eqs 14 and 15, the parallel capacitance of the specimen is:

$$C_p = C' - C_r + C_{ar} \quad \dots\dots\dots (16)$$

provided the edge capacitances, C_{ep} and C_{er}, are the same.

When a standard capacitor is used, Eq 9, following Eq 14, becomes:

$$C'' = C_N + C_p + C_r' - C_{ar} + C_0 + C_{ep} \quad . (17)$$

When the specimen is removed, the grounded electrode is set at the spacing, r, which it had when the specimen was clamped between the electrodes. Equation 10, following Eq 15, becomes:

$$C'' = C_{Nr}' + C_r' + C_0 + C_{er} \quad \dots\dots (18)$$

Combining Eqs 17 and 18, the parallel capacitance of the specimen is:

$$C_p = C_{Nr}' - C_N + C_{ar} \quad \dots\dots\dots (19)$$

provided the edge capacitances, C_{ep} and C_{er}, are the same.

The errors involved in measurements with a micrometer-electrode system are somewhat more difficult to evaluate than those with a guard electrode. With the specimen the same size as the electrodes, the error caused by edge capacitance and nonuniform field may be as large as 1 per cent. This will include the effect of an irregular edge or of imperfect centering of the specimen in the electrodes. These errors probably vanish when the specimen is sufficiently smaller than the electrodes. There remains in any case an error amounting possibly to several tenths of 1 per cent caused by imperfect adjustment of the micrometer screw, upon which the calibration capacitance, C_t or C_r, and standard capacitance, C_{Nt}' or C_{Nr}', depend. Since the errors occurring in the dimensions of the specimen are about the same for any method of capacitance measurement, the over-all error in the determination of the dielectric constant of a solid by this method is between 0.5 and 1.0 per cent, depending on the thickness of the specimen. In any comparison of the two systems on the basis of measuring electrodes having the same diameter, the micrometer-electrode system is perhaps a few tenths of 1 per cent inferior to the guard-electrode system, whereas, on the basis of specimens of equal diameter, the micrometer-electrode system may be superior. However, under conditions of high relative humidity, where a surface water film can produce interfacial polarization at the edge of the specimen, a guard electrode must be used.

SERIES AIR OR OIL CAPACITANCES

The effect of series capacitance, produced either by the air capacitance of poor contact between the specimen and rigid electrodes or by petrolatum or other adhesive, has been studied in considerable detail by measuring a set of cross-linked polystyrene disks that were prepared by E. B. Baker of Dow Chemical Co. Nine disks with nominal diameters of 2, 1½, and 1⅜ in. and nominal thicknesses of ¼, $\frac{3}{16}$, ⅛, and $\frac{1}{16}$ were used. Their exact dimensions, as measured by steel scale and microscope for diameter and by dial gage for thickness, are given in the first two columns of Table II.

Baker reported that these specimens were ground on a modified abrasion machine originally designed at the National Bureau of Standards and that their surfaces are

TABLE II.—DIMENSIONS OF THE DISKS.

Diameter, in. *1*	Thickness, in. *2*	Maximum Deviation, in. *3*	Maximum Thickness, in. *4*	Dial Reading, in. *5*	C_V, μμf *6*	$\frac{c}{t}$ *7*
2.000	0.2500	0.0002	0.2501	0.2504	2.826	0.00
2.000	0.1864	0.0007	0.1868	0.1869	3.790	0.00
2.000	0.1247	0.0006	0.1251	0.1250	5.666	0.00
2.000	0.0632	0.0006	0.0636	0.0635	11.179	0.00
1.506	0.2407	0.0003	0.2409	0.2412	1.664	1.02
1.506	0.1821	0.0002	0.1822	0.1826	2.200	1.35
1.503	0.1224	0.0003	0.1226	0.1225	3.260	2.03
1.503	0.0601	0.0002	0.0602	0.0604	6.639	4.13
1.344	0.0571	0.0002	0.0572	0.0574	5.588	5.72

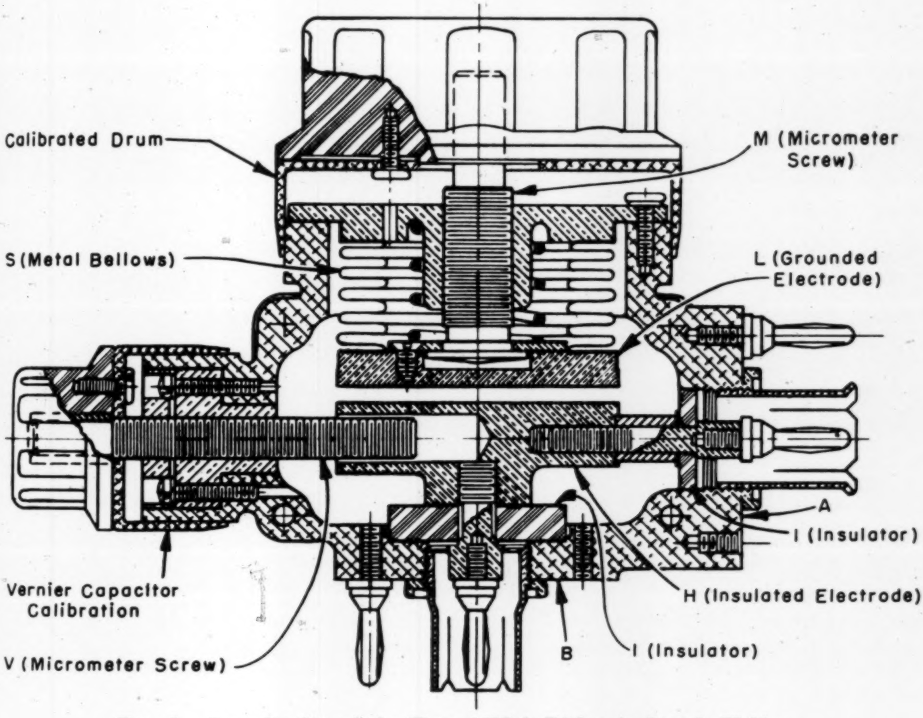
Calibrated Drum
M (Micrometer Screw)
S (Metal Bellows)
L (Grounded Electrode)
A
I (Insulator)
H (Insulated Electrode)
Vernier Capacitor Calibration
B
I (Insulator)
V (Micrometer Screw)

FIG. 3.—Cross-Section of the Type 1690-A Dielectric Sample Holder.

plane and parallel within 0.0001 in. The maximum deviations shown in column 3 are larger than this figure. The really large deviations occur in the 2-in. diameter disks and always at their center. The abrasion machine was designed for 1½-in. diameter disks, and some difficulty was encountered with the larger diameter. It is also possible that some error came from the use of a dial gage for which the last figure was estimated. The direct interelectrode vacuum capacitances of the specimens, as calculated from Eq 3, are given in column 6.

TABLE III.—DIELECTRIC CONSTANT OF SPECIMENS UNDER DIFFERENT CONDITIONS.[a]

$1/t$, 1/in.	Condition A	Condition B	Condition C	Condition D	Condition E	Condition F	Condition G
4.000	2.507	2.526	2.543	2.543	2.527	2.546	2.545
5.365	2.512	2.521	2.542	2.545	2.515	2.544	2.540
8.019	2.485	2.476	2.537	2.539	2.499	2.537	2.542
15.823	2.434	2.440	2.543	2.546	2.466	2.541	2.550
4.155	2.496	2.517	2.527	2.527	2.517	2.525	2.535
5.491	2.494	2.501	2.522	2.524	2.510	2.520	2.534
8.170	2.476	2.509	2.524	2.526	2.507	2.521	2.532
16.639	2.440	2.452	2.501	2.509	2.461	2.511	2.528
17.513	2.426	2.456	2.494	2.501	2.451	2.499	2.520
K_0:							
2.0-in. specimen[b]	2.540	2.555	2.540	2.541	2.542	2.543	2.537
1.5-in. specimen[c]	2.517	2.538	2.538	2.535	2.542	2.528	2.537
a, mil:							
2.0-in. specimen	1.0	2.2			0.7		
1.5-in. specimen	0.7	1.6	0.7	0.5	0.7	0.3	0.1

[a] A = bare. B = No. 4 ignition sealing compound or DC200 silicone oil. C = foil, 0.35 mil. D = less DC200 oil. E = bare. F = foil, 0.35 mil. G = 2 months later.

[b] C, D, F, G average = 2.540.

[c] C, D, F, G average = 2.534.

Capacitances were measured on a General Radio Co. Type 1610-A Capacitance Measuring Assembly in terms of a Type 1690-A Dielectric Sample Holder and the 100 $\mu\mu$f section of a Type 722-D Precision Capacitor, which was provided with a worm correction. A cross-section of the Type 1690-A Dielectric Sample Holder is shown in Fig. 3. Its electrodes are plane within a few wavelengths of light and are adjusted to be parallel within 0.0002 in. In addition the grounded electrode is disengaged from its drive mechanism on contact with the specimen and is free to set itself parallel to the specimen's upper surface under a pressure of 12 to 15 lb. The dial of the micrometer screw can be read to 0.0001 in. by estimating fifths of a division. The accuracy of the adjustment of this dial is shown by comparing columns 4 and 5 of Table II. The readings of the dial exceed the maximum thicknesses by only 0.0001 in. on the average and with a maximum of 0.0004 in.

The specimens were measured under seven different conditions. With the specimen removed, the grounded electrode was returned to the spacing, r, that it had with the specimen in place, as required by Eq 19. The distinction between vacuum and air capacitance was recognized in calculating values for C_{ar} and C_v. The values of dielectric constant thus obtained are given in Table III, arranged in the same order as that used in Table II.

The specimens were first measured bare (condition A). It is immediately apparent from the way in which dielectric constant decreases with decreasing thickness that there is a considerable series capacitance.

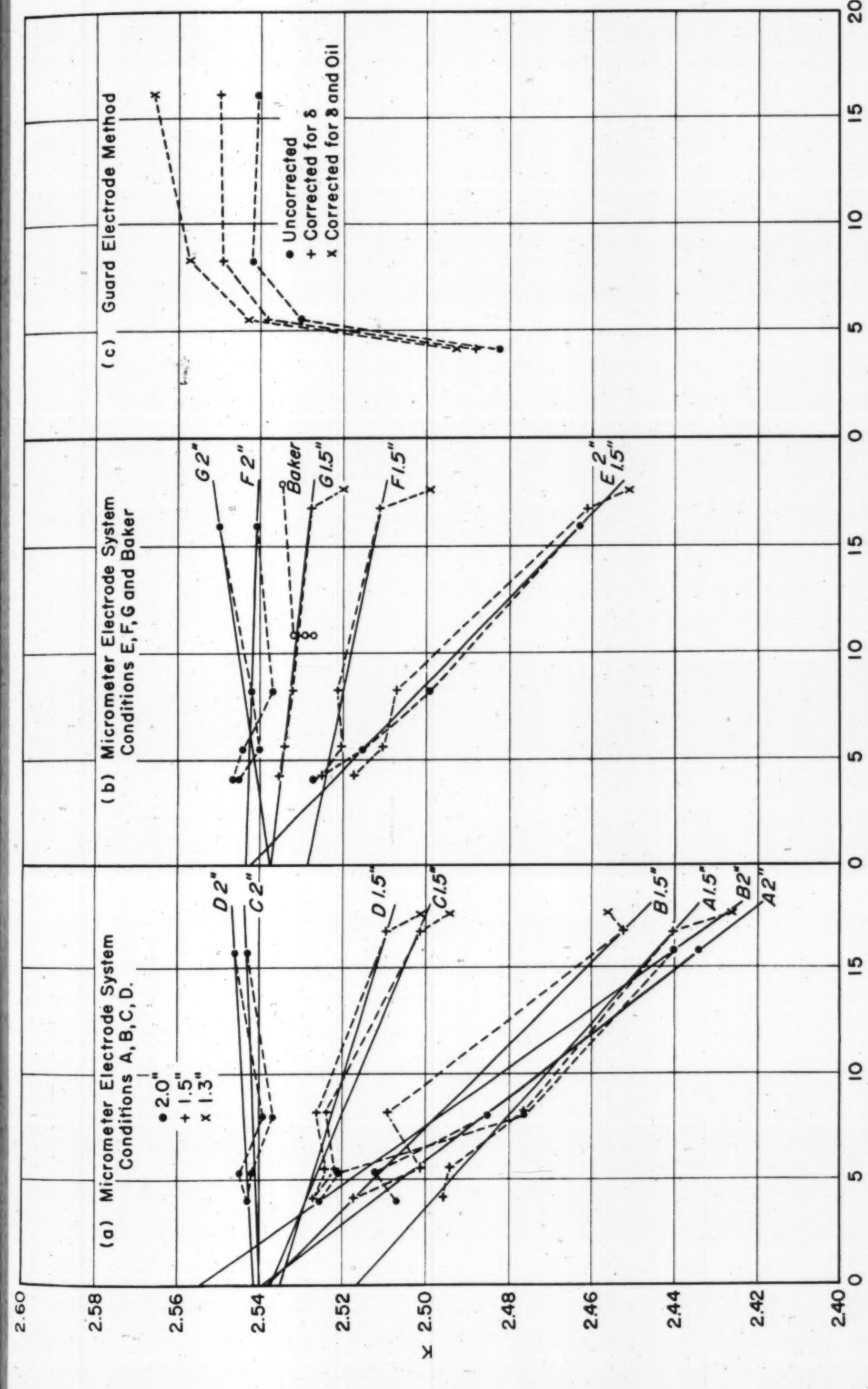

FIG. 4.—Dielectric Constant, Polystyrene Specimens.

It can be easily shown that for any series film of thickness, a, and dielectric constant, K_a, the observed dielectric constant, K, will be related to the real dielectric constant, K_0, by the expression:

$$\frac{1}{K} = \frac{a}{K_a t} + \frac{1}{K_0} \quad \text{..........} \quad (20)$$

When plotted with $1/K$ and $1/t$ as coordinates, this a straight line with slope a/K_a and intercept $1/K_0$. It is preferable, however, to plot K against $1/t$, because of the other errors caused by the variability of edge capacitance and nonuniformity of field between the electrodes.

$$K = -\frac{K_0^2 a}{K_0 a + K_a t} + K_0$$

$$= -\frac{K_0^2 a}{K_a t} + K_0 \text{ (approximate)} \ldots (21)$$

This is also a straight line to the accuracy of the observations, with slope $-K_0^2 a/K_a$ and intercept K_0. For an air film, K_a is unity. The data shown in Table III are thus plotted in Fig. 4 (*a*) and (*b*). The points are considerably scattered, but it must be remembered that each point is from a different specimen. It would be surprising if all the surfaces were so uniformly irregular as to result in the same thickness of air film. The straight lines that best represent the points are drawn, and values of K_0 and a calculated. These values are given in the last four rows of Table III. Average values of K_0 for the case of foil electrodes are 2.540 for 2-in. and 2.534 for 1.5-in. diam specimens. In the case of the bare specimens (condition A), an air film of 1.0 mil is indicated for the 2-in. and 0.7 mil for the 1.5-in. specimens. These values are considerably larger than even the maximum deviations shown in Table II, particularly for the smaller specimens, and some other explanation must be sought. It perhaps exists in the fact that the surfaces of the specimens were not polished. This would leave a multitude of fine air pockets below the surface measured by the relatively large probe of a dial gage.

The specimens were next coated (condition B), some with Dow Corning No. 4 ignition sealing compound and some with DC 200 silicone oil having a viscosity of 100 centistokes and a dielectric constant of 2.0. The oil was much easier to handle and was used thereafter. The use of the oil increased both the indicated dielectric constant and the slope of the lines. An adhesive film of 2.2 mil is indicated for the 2-in. specimens and 1.6 mil for the 1.5-in. specimens. Use of an adhesive alone is of no help in reducing the effect of series capacitance. This would be even more noticeable with specimens having a high dielectric constant.

Lead foil, having a thickness of 0.35 mil, was then applied (condition C), and the micrometer electrodes cleaned of oil. The slopes of the lines are much reduced, that for the 2-in. specimens being essentially zero. There is a definite difference in behavior between specimens of different diameter. The slope of the line for the smaller specimens indicates an oil thickness of 0.7 mil. The slightly positive slope of the line for the 2-in. specimens is produced by the changes in edge capacitance and uniformity of field between the electrodes with and without the specimen. The divergence of these two lines measures the error when the specimen is the same size as the electrodes. This error varies inversely with the thickness of the specimen and can be expressed roughly as $+0.1/t$ per cent.

The foils were removed, some excess oil was wiped off with a cloth, and the foils then replaced (condition D). This reduced the indicated thickness of the oil film to 0.5 mil. The fact that the points for conditions C and D, though scattered, follow the same pattern indicates that slight errors were made in the thickness or area measurement or both.

The foils were again removed, the oil thoroughly wiped off, and the specimens measured bare (condition E). The plotted points in Fig. 4(*b*) are more consistent than for the similar case in Fig. 4(*a*). The lines for the two sizes of specimens are identical and indicate a film thickness of 0.7 mil, being the same as that found previously for the smaller specimens.

When foils were applied again (condition F), there was a noticeable reduction of the slope for the smaller specimens to an oil thickness of 0.3 mil.

Other measurements were made on the specimens, during which a gap was cut in one electrode of the 2-in. specimens for three-terminal measurements, and then a week later new foils were applied. Two months later all the specimens were remeasured (condition G). There is a marked decrease in the slope for the smaller specimens and the oil film is reduced to 0.1 mil, whereas for the larger specimens, dielectric constant increases with decreasing thickness. The indicated error for a specimen the same size as the electrodes is reduced to $+0.05/t$ per cent, which is an error of +0.8 per cent for a thickness of $\frac{1}{16}$ in. and +0.2 per cent for $\frac{1}{4}$ in. Since the points seem to fall on a straight line up to a thickness of $\frac{1}{4}$ in., the electrodes need only extend beyond the specimen by the specimen's thickness to make this error negligible. Values of the ratio c/t, where c is the extension of the electrodes beyond the specimen, are given in the last column of Table II for all the specimens. To a certain extent this conclusion can hold only for the micrometer-electrode system used and for a dielectric constant of 2.5. More observations are certainly needed for materials of higher dielectric constant.

TABLE IV.—DIELECTRIC CONSTANT OF SIMILAR SPECIMENS BY BAKER.

Diameter, in.	t, in.	K	$\frac{c}{t}$
1.347.......	0.0562	2.535	1.36
1.348.......	0.0937	2.529	0.81
1.253.......	0.0937	2.527	1.32
1.168.......	0.0937	2.532	1.77

A moderate confirmation of these conclusions is provided by Baker.[4] He has measured specimens of this same polystyrene on his automatic-balancing equipment (**10**), which uses electrodes of 1.5 in. diam. For bare specimens $\frac{1}{16}$ in. thick, he found a dielectric constant of 2.46. For specimens with deposited silver electrodes, values of diameter, thickness, dielectric constant, and the ratio c/t are given in Table IV and shown in Fig. 4(*b*).

The process of chemically depositing silver on a ground surface should give perfect contact with the specimen and will tend to give values of dielectric constant on the high side, because the thickness used to calculate vacuum capacitance, C_v, will be too large. Combining these values of dielectric constant with those reported in this paper, a reasonable value appears to be 2.535 ±0.1 per cent.

The sets of observations that have been described show not only that some type of thin metallic electrode is necessary, but that the use of foil can introduce a considerable error. Conducting paint or metal deposited in a way to obtain perfect contact with the surface of the specimen is preferable. It also appears that the surfaces of the specimen should be polished, so that the entire surface is optically plane.

A few measurements were made with a fused quartz disk 2 in. in diameter and 0.0608 in. thick, whose surfaces were optically plane and parallel. Its dielectric constant was found to be 3.668 for the bare specimen and 3.817 when foil was applied. These values should be high by 0.8 per cent because the specimen is the same size as the micrometer electrodes. The second value should be low by 0.9 per cent because the reading of the micrometer screw indicated that the oil film was 0.3 mil thick. This indicates a value of 3.820 for dielectric constant. A comparison of this value with that obtained with the bare specimen gives an air film thickness of 0.6 mil. This is only about half the value obtained for the polystyrene specimens when first measured, and slightly less than was found after oil had been applied and then rubbed off. Something in the measurement technique is preventing complete contact with the specimen. Perhaps the various surfaces had not been kept sufficiently free of dust and lint. Measurements on a set of optically flat fused quartz specimens of different diameters and thicknesses and provided with deposited metal electrodes would go far toward solving these problems.

In the course of one set of measurements on the smaller specimens, observations were taken in terms of both the Type 722-D Precision Capacitor and the Type 1690-A Dielectric Sample Holder. The resulting values of dielectric constant differ by 0.25 per cent on the average, with a maximum difference of 0.48 per cent, with the standard capacitor giving the larger values. To some extent this confirms an earlier statement that errors in capacitance measurements with a micrometer-electrode system may be as great as 0.5 per cent.

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[4] E. B. Baker, letter to R. F. Field, April 16, 1952.

TABLE V.—GUARD ELECTRODE MEASUREMENTS.

$1/t$, 1/in. 1	d, in. 2	g, in. 3	c, in. 4	c/t 5	g/t 6	δ/t 7	δ, in. 8	K without δ 9	K with δ 10	K, oil 11
4.000....	1.761	0.029	0.090	0.36	0.116	0.0026	0.00065	2.482	2.488	2.492
5.365....	1.765	0.024	0.094	0.50	0.129	0.0032	0.00060	2.530	2.538	2.543
8.019....	1.761	0.028	0.092	0.74	0.225	0.0097	0.00124	2.542	2.549	2.557
15.823....	1.765	0.023	0.094	1.49	0.363	0.0250	0.00158	2.541	2.550	2.566

TABLE VI.—TWO-TERMINAL MEASUREMENTS WITH WIRE CONNECTOR.

t, in. 1	C_v, μμf 2	C_p, μμf 3	K 4	C_e, μμf 5	C_g, μμf 6	$C_e + C_g$, μμf 7	$C_p - (C_e + C_g)$, μμf 8	K 9	$C_p - C_e$, μμf 10	K 11
0.2500...	2.826	8.040	2.845	0.640	0.898	1.538	6.502	2.301	7.400	2.619
0.1864...	3.790	10.565	2.788	0.696	0.898	1.594	8.971	2.367	9.869	2.604
0.1247...	5.666	15.342	2.708	0.920	0.898	1.818	13.524	2.387	14.422	2.545
0.0632...	11.179	29.532	2.642	1.199	0.898	2.097	27.435	2.454	28.333	2.535
0.2407...	1.664	4.807	2.889	0.493	0.676	1.169	3.638	2.186	4.314	2.593
0.1821...	2.200	6.150	2.795	0.578	0.676	1.254	4.896	2.225	5.572	2.533
0.1224...	3.260	8.908	2.733	0.696	0.676	1.370	7.538	2.312	8.212	2.519
0.0601...	6.639	17.463	2.630	0.912	0.676	1.586	15.877	2.391	16.551	2.493
0.0571...	5.588	14.657	2.623	0.828	0.603	1.431	13.226	2.367	13.829	2.475

GUARD ELECTRODE METHOD WITH THREE-TERMINAL CELL

After the measurements under condition F of Table III were made, a guard electrode was provided for the 2-in. specimens by cutting a gap in the foil on one surface with a specially sharpened compass. The dimensions of the resulting specimens are given in Table V. A gap width, g, of 0.02 in. is about the smallest that can be cut in thin metal foil, but even this width produces an appreciable fringing constant, δ, as calculated from Eq 5 and given in column 8. Capacitances were measured by placing the specimens in a three-terminal cell similar to that shown in Fig. 1, but having an internal diameter of only 3 in. It is possible that this small size affected the measurements. Values of dielectric constant calculated without and with the fringing constant, δ, are given in columns 9 and 10 of Table V and are plotted in Fig. 4(c). The greatest increase in K due to this constant occurs for the thinnest specimen and amounts to 0.4 per cent. The large decrease in K for the thicker specimens occurs because of an insufficient width, c, of the guard electrode. Values of the ratio c/t are given in column 5. Even so, the error introduced is apparently much less than that predicted by Moon and Sparks (1). It seems to become negligible when c/t equals unity.

The values of dielectric constant so obtained, 2.541 without the fringing correction and 2.550 with it, are larger than the value of 2.535 found with micrometer electrodes. In addition it must be remembered that for these specimens there was an oil film 0.32 mil thick, which causes the dielectric constant of the thinnest specimen to be about 0.6

per cent low. The values of dielectric constant obtained by applying this type of correction are given in the last column of Table VI. They suggest that the true value is nearly 2.57, a value 1.5 per cent above 2.535. It is unfortunate that, as originally intended, other measurements were not made with larger guard widths, and also two months later with the thinner oil film and in the larger cell then used for obtaining edge capacitance.

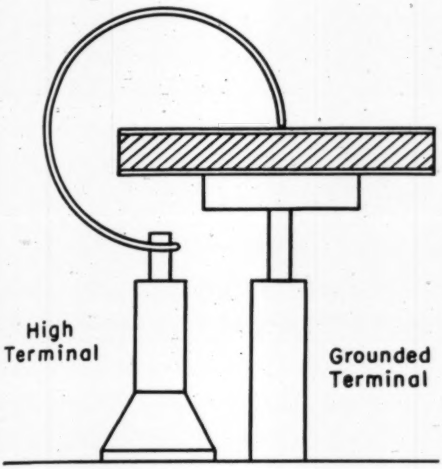

FIG. 5.—Stiff Wire Connector for Two-Terminal System.

TWO-TERMINAL METHOD WITH WIRE CONNECTOR

A third method for determining the dielectric constant of a solid dielectric consists in applying thin metal electrodes to the specimen and measuring its capacitance as a two-terminal capacitor. Included in the measured capacitance is an edge capacitance, C_e, produced by fringing between the electrodes either in air or in the dielectric when it extends beyond the electrodes, and a ground capacitance, C_g, of the high electrode to ground.

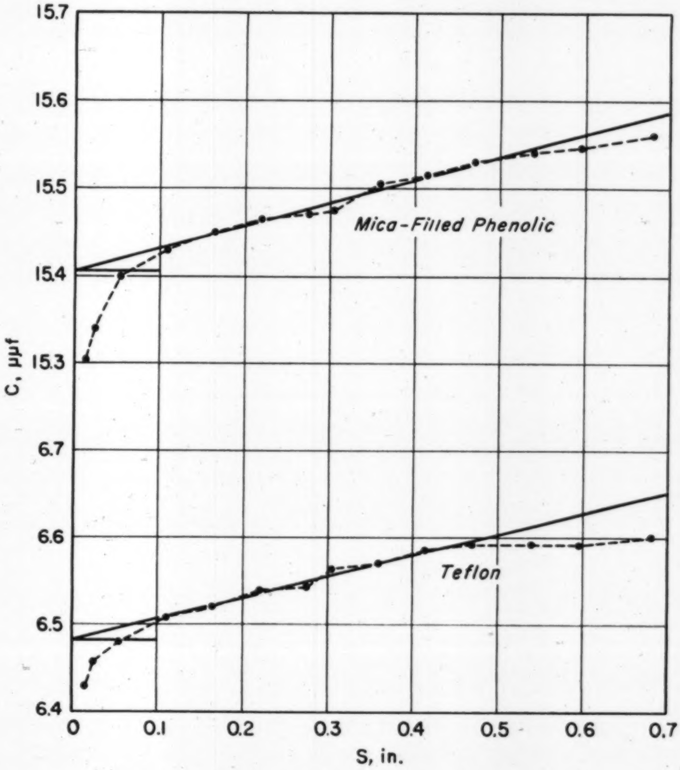

FIG. 6.—Correct Spacing for Wire Connector.

Connection Error:

There will also be an error involved in making connection to the high electrode. Field (**11**) has shown how this error can be reduced to less than 0.02 $\mu\mu$f by the use of a fine stiff bare wire. After the first capacitance measurement is made with the specimen connected, the wire is lifted slightly from the high electrode by bending or pivoting at its other end, and the circuit is rebalanced. The exact amount of lift necessary to minimize the error can be found by measuring the capacitance for different spacings varying from 0.01 to 0.5 in. For a long wire and a capacitor with terminals mounted on a large panel (**11**), this spacing is about $\frac{1}{4}$ in. With a 2-in. diam. specimen mounted as shown in Fig. 5, which uses a copper wire bent into an arc of $\frac{3}{4}$ in. radius and rounded at the point of contact, the spacing is only about $\frac{1}{16}$ in. Two sets of measurements were made on specimens $\frac{1}{4}$ in. thick, a mica-filled phenolic with a dielectric constant of 5.3 and teflon with a dielectric constant of 2.03. The calculated capacitances are plotted in Fig. 6 for different spacings, *s*. The intercept of the slanting asymptote of the resulting curve is the correct capacitance. The pro-

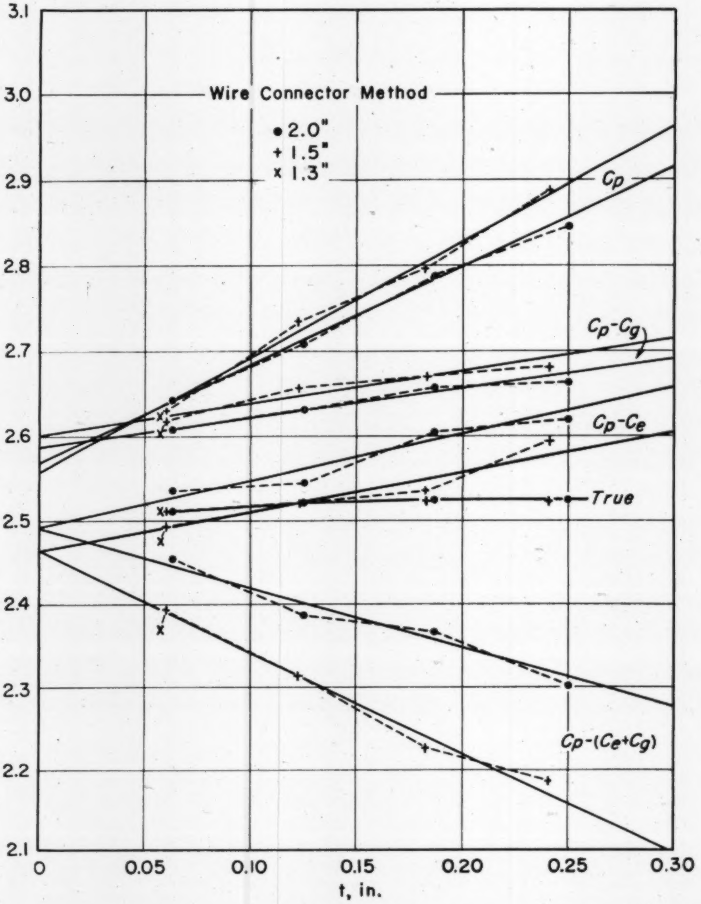

FIG. 7.—Dielectric Constant, Polystyrene Specimens, Wire Connector Method.

jection of this value back onto the curve gives the proper spacing. The way in which the curves fall off from their slanting asymptotes beyond a spacing of 0.5 in. emphasizes the importance of minimizing the over-all movement of the wire.

Edge and Ground Capacitances:

The specimens were measured by this method after the three-terminal measurements were made and when new foils had been applied to the 2-in. specimens. The calculated values of capacitance and dielectric constant are given in columns 3 and 4 of Table VI. It is obvious from the magnitude of the values of dielectric constant shown in column 4 as compared to 2.535 that the edge and ground capacitances are quite large. The best expressions at present for edge and ground capacitance are those contained in ASTM Method D 150.[5]

TABLE VII.—EDGE AND GROUND CAPACITANCES.

t, in.	C_v, μμf	C_p, μμf	K	K, true	C, μμf	C_e, μμf	C_g, μμf
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*
0.2500	2.826	7.523	2.662	2.524	7.133	0.390	0.517
0.1864	3.790	10.066	2.656	2.523	9.562	0.504	0.499
0.1247	5.666	14.902	2.630	2.520	14.278	0.624	0.440
0.0632	11.179	29.156	2.608	2.512	28.082	1.074	0.376
0.2407	1.664	4.458	2.679	2.524	4.200	0.258	0.349
0.1821	2.200	5.870	2.668	2.523	5.551	0.319	0.280
0.1224	3.260	8.656	2.655	2.520	8.215	0.441	0.252
0.0601	6.639	17.302	2.617	2.511	16.671	0.631	0.161
0.0571	5.588	14.537	2.601	2.510	14.026	0.511	0.120

$$C_e = \left(0.147 \log \frac{0.59}{t} + 0.047\right) P \text{ μμf (in.)} \quad (22)$$

$$C_g = 0.449\, d \text{ μμf (in.)} \quad (23)$$

where P is the perimeter of the specimen. Their values are given in columns 5 and 6 and their sum in column 7 of Table VI. Values of capacitance and dielectric constant calculated from these values are given in columns 8 and 9. When the values of dielectric constant are plotted, as in Fig. 7, it is seen that the corrected values are nearly as low as the uncorrected values are high. Extrapolating back to zero thickness, there is a range of values of dielectric constant from 2.465 to 2.567, with an average of 2.520.

The edge capacitance expression of Eq 22 was derived by Scott and Curtis (12) and can be in error for small specimens because it was derived from specimens 6 in. in diameter. The ground capacitance expression of Eq 23 is one half the capacitance to free space of an infinitely thin circular disk. It has never been verified experimentally as applying to the high electrode of a dielectric specimen. In fact, better values of dielectric constant will be obtained by omitting it, as is shown by the values given in columns 10 and 11 of Table VI and by the plot of dielectric constant in Fig. 7.

The difficulty in obtaining consistent expressions for edge and ground capacitance arises from the fact that these two capacitances, as normally defined, conflict. The lines of force that represent edge capacitance extend above the plane of the high electrode into the space reserved for the lines representing ground capacitance. This conflict will be further accentuated by the existence of a ground plane a short distance below the dielectric specimen, rather than at infinity. Values of edge capacitance are found experimentally by measuring the specimens in a three-terminal cell. This removes the ground capacitance completely and leaves the edge capacitance as the difference of the capacitance thus measured and that obtained from micrometer or guard electrodes. The three-terminal cell must be large enough not to alter the edge capacitance by carrying a portion of it to the guard terminal.

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[5] Tentative Methods of Test for Power Factor and Dielectric Constant of Electrical Insulating Materials (D 150 – 47 T), 1952 Book of ASTM Standards, Part 6, p. 936.

A circular three-terminal cell was constructed 9 in. in diameter and 3 in. deep, giving an edge clearance of 3.5 in. and a face clearance of 1.5 in. The capacitances of the set of specimens, as measured in this cell (the average of two separate determinations), are given in column 3 of Table VII. The corresponding values of dielectric constant are given in column 4 and are plotted in Fig. 7 as $(C_p - C_g)$. They are, of course, too high because they include the edge capacitance. The true values of dielectric constant for these specimens are given in column 5 and are also plotted in Fig. 7. They are taken from the straight line in Fig. 4(*b*) that represents the data taken under condition F for the 1.5-in. diameter specimens. These values are used rather than 2.535 because they take into account the effect of the oil film. The corresponding values of capacitance are given in column 6. The differences between these capacitances and the observed values in column 3 are the edge capacitances, C_e, in column 7. They are about two thirds of the values calculated by Eq 22. The differences of the observed values in columns 3 of Tables VI and VII are the ground capacitances in column 8. They vary markedly with thickness and are much less than the values calculated by Eq 23 and given in column 6 of Table VI.

TABLE VIII.—EDGE CAPACITANCE, ELECTRODES TO EDGE OF SPECIMEN.

Material	K	d, in.	P, in.	t, in.	$\log \frac{P}{t}$	C_e, μμf	$\frac{C_e}{P}$, $\frac{\mu\mu f}{in.}$
	1	*2*	*3*	*4*	*5*	*6*	*7*
Polystyrene.......	2.524	2.000	6.283	0.2500	1.400	0.390	0.0620
	2.523	2.000	6.283	0.1864	1.528	0.504	0.0802
	2.520	2.000	6.283	0.1247	1.702	0.624	0.0992
	2.512	2.000	6.283	0.0632	1.998	1.074	0.1709
Polystyrene.......	2.524	1.506	4.731	0.2407	1.293	0.258	0.0545
	2.523	1.506	4.731	0.1821	1.414	0.319	0.0674
	2.520	1.503	4.722	0.1224	1.587	0.441	0.0934
	2.511	1.503	4.722	0.0601	1.896	0.631	0.1336
Polystyrene.......	2.510	1.344	4.222	0.0571	1.869	0.511	0.1210
Polystyrene.......	2.540	6.000	18.850	0.2031	1.968	2.292	0.1217
	2.527	6.000	18.850	0.2035	1.967	2.320	0.1231
	2.531	6.000	18.850	0.2035	1.967	2.355	0.1250
	2.541	6.000	18.850	0.2022	1.969	2.358	0.1251
	2.528	6.000	18.850	0.2039	1.966	2.340	0.1242
	2.532	6.000	18.850	0.1268	2.172	2.803	0.1488
Polystyrene.......	2.541	4.004	12.579	0.2558	1.692	1.257	0.1000
	2.539	4.003	12.576	0.0650	2.287	2.040	0.1622
Methacrylate......	3.187	3.996	12.554	0.2544	1.693	1.187	0.0945
	3.200	4.000	12.566	0.0646	2.289	1.123	0.0893
Butvar...........	3.342	4.007	12.588	0.2514	1.699	1.190	0.0945
	3.257	4.004	12.579	0.0632	2.299	1.453	0.1155

Edge Capacitance:

The classic expression for edge capacitance is that of Kirchhoff (**13**) for thick electrodes extending to the edge of the specimen. It is based entirely on theoretical considerations. Reducing this to the case of infinitely thin electrodes:

$$\frac{C_e}{P} = 0.0826 \log \frac{P}{t} - 0.0332 \frac{\mu\mu\text{f}}{\text{in.}} \ldots (24)$$

where P is the perimeter of the electrodes.

The expression developed by Scott and Curtis (12):

$$\frac{C_e}{P} = 0.147 \log \frac{0.59}{t} + 0.047 \frac{\mu\mu f}{\text{in.}} \ldots (25)$$

differs from Kirchhoff's by not including the perimeter P in the logarithmic term. This occurred because, for this type of electrode, only 6-in. diam specimens were measured. Using this value to determine perimeter P, Eq 25 becomes:

$$\frac{C_e}{P} = 0.147 \log \frac{P}{t} - 0.174 \frac{\mu\mu f}{\text{in.}} \ldots . (26)$$

There are now available for checking Kirchhoff's formula and for obtaining new values of the coefficients, if necessary, the values of edge capacitance given in column 7 of Table VII and further data provided by A. H. Scott[6] and given in Table VIII· Scott's data are for 4- and 6-in. diam specimens of polystyrene, methyl methacrylate, and butvar. Each set is the average of measurements of at least three similar specimens. Values of log P/t and C_e/P are

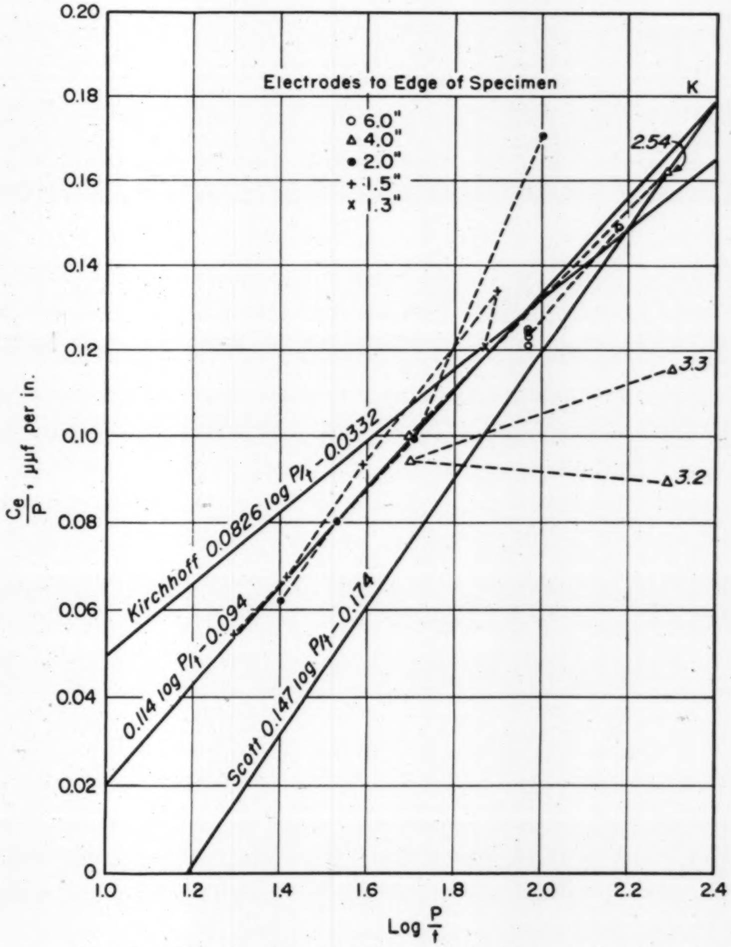

FIG. 8.—Edge Capacitance, Electrodes to Edge of Specimen.

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[6] A. H. Scott, letter to R. F. Field, April 18, 1952.

given in columns 5 and 7 of Table VIII and are plotted in Fig. 8. With a few exceptions the points fall on the straight line defined by:

$$\frac{C_e}{P} = 0.114 \log \frac{P}{t} - 0.094 \frac{\mu\mu\text{f}}{\text{in.}} \quad \ldots . (27)$$

TABLE IX.—EDGE CAPACITANCE, ELECTRODES SMALLER THAN SPECIMEN.

Material	K	d, in.	P, in.	t, in.	$\log \frac{P}{t}$	Equal Electrodes		Unequal Electrodes	
						C_e, $\mu\mu$f	$\frac{C_e}{KP}$, $\frac{\mu\mu\text{f}}{\text{in.}}$	C_e, $\mu\mu$f	$\frac{C_e}{KP}$, $\frac{\mu\mu\text{f}}{\text{in.}}$
Polystyrene	2.58	4.291	13.48	0.2571	1.719	2.29	0.0658	5.65	0.1624
	2.57	4.291	13.48	0.1865	1.859	2.47	0.0712	5.86	0.1688
Hard rubber	3.12	4.291	13.48	0.1854	1.862	3.29	0.0782	6.92	0.1645
Methacrylate	3.29	4.291	13.48	0.2742	1.691	2.88	0.0648	6.64	0.1499
	3.31	4.291	13.48	0.1838	1.865	3.08	0.0689	6.98	0.1565
	3.28	4.291	13.48	0.1016	2.123	3.67	0.0802	7.64	0.1725
	3.32	4.291	13.48	0.0319	2.626	4.66	0.1042	9.22	0.2060
Aniline	3.71	4.291	13.48	0.1189	2.055	3.67	0.0733	8.32	0.1665
Acetate	5.14	4.291	13.48	0.1228	2.040	4.56	0.0658	9.90	0.1427
Porcelain	6.19	4.291	13.48	0.2350	1.759	5.24	0.0627	11.10	0.1330
Glass	7.76	4.291	13.48	0.1838	1.865	6.06	0.0580	13.19	0.1260
Marble	8.60	4.291	13.48	0.2982	1.657	6.24	0.0537	13.97	0.1206
	8.75	4.291	13.48	0.2768	1.688	6.13	0.0520	14.11	0.1197
Titania	14.2	4.291	13.48	0.2392	1.751	11.00	0.0574	22.70	0.1186
	15.7	4.291	13.48	0.1008	2.126	12.50	0.0590	24.76	0.1170
Titania	54.0	4.291	13.48	0.2460	1.739	37.48	0.0514	77.60	0.1065
	57.4	4.291	13.48	0.2319	1.764	38.20	0.0494	81.68	0.1056
	57.0	4.291	13.48	0.2180	1.791	37.48	0.0487	78.40	0.1020
	57.1	4.291	13.48	0.0980	2.138	35.32	0.0459	78.94	0.1025
Titania	70.5	3.110	9.77	0.2397	1.611	28.32	0.0411	72.64	0.1055
	68.5	3.110	9.77	0.1079	1.957	35.42	0.0529	71.14	0.1062
	70.6	3.110	9.77	0.0559	2.243	39.81	0.0577	73.98	0.1066

In spite of the three points that are completely out of line, there is no evidence that this edge capacitance is a function of dielectric constant. Omitting these same three points, the average error, when Eq 27 is applied to these specimens, is 3.9 per cent and the maximum error is 8.5 per cent. The line representing the Kirchhoff equation, Eq 24, is also drawn. The difference between the two expressions is important mainly for specimens less than 3 in. in diameter. The modified Scott and Curtis Eq 26 is plotted in Fig. 8 as a considerably steeper line that agrees with the others only for large values of log P/t.

Scott and Curtis (12) also obtained expressions for edge capacitance when the specimen extends beyond one or both electrodes.

Equal Electrodes:

$$\frac{C_e}{P} = 0.147\, K \log \frac{0.59}{t} + 0.047 \frac{\mu\mu\text{f}}{\text{in.}} \quad \ldots (28)$$

Unequal Electrodes:

$$\frac{C_e}{P} = 0.195\, K \log \frac{1.5}{t} + 0.103 \frac{\mu\mu\text{f}}{\text{in.}} \quad \ldots (29)$$

The measurements were made on nine different materials with dielectric constants ranging from 2.5 to 70. Significant data for these specimens are collected in Table IX. The quantity C_e/KP is calculated in order

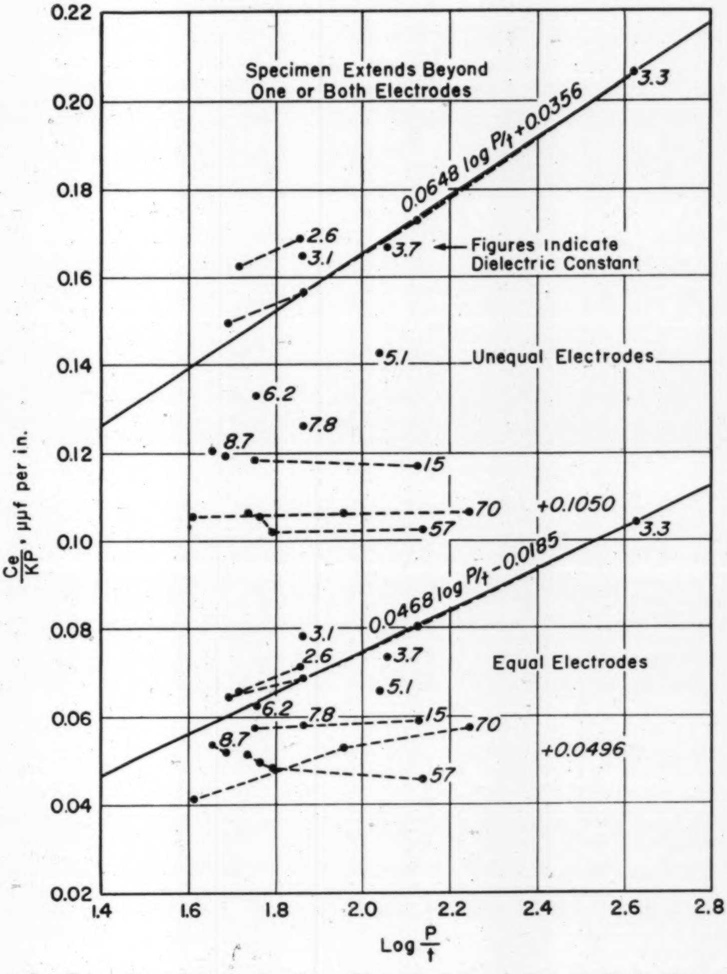

FIG. 9.—Edge Capacitance, Specimen Extends Beyond One or Both Electrodes.

TABLE X.—EDGE CAPACITANCE, SLOPES AND INTERCEPTS.

K	$\frac{1}{K}$	Equal Electrodes		Unequal Electrodes	
		s	b	s	b
3.30	0.303	0.0468	−0.0185	0.0648	+0.0356
∞	0.000	0.0000	+0.0496	0.0000	+0.1050
Linear Relation		$\frac{0.153}{K}$	$-\frac{0.225}{K}+0.0496$	$\frac{0.214}{K}$	$-\frac{0.229}{K}+0.1050$

to include the effect of dielectric constant. Values of this quantity are plotted against log P/t in Fig. 9. For equal values of dielectric constant, it appears to be a linear function of log P/t, just as was found to be the case for electrodes extending to the edge of the specimen. It is unfortunate that only for a dielectric constant of 3.3 are there sufficient observations to define a line accurately. The slopes of the lines decrease with increasing value of dielectric constant and have become nearly zero for $K = 57$. Any line will have the equation:

TABLE XI.—GROUND CAPACITANCE.

t, in.	C_p, μμf					C, μμf	C_g, μμf				
	$h =$ 0.625 in.	$h =$ 1.875 in.	$h =$ 3.000 in.	$h =$ 5.125 in.	$h =$ 8.625 in.		$h =$ 0.625 in.	$h =$ 1.875 in.	$h =$ 3 in.	$h =$ 5.125 in.	$h =$ 8.625 in.
1	2	3	4	5	6	7	8	9	10	11	12
0.2500...	8.216	8.028	7.980	7.906	7.837	7.523	0.693	0.505	0.457	0.383	0.314
0.1864...	10.709	10.561	10.477	10.439	10.364	10.066	0.643	0.495	0.411	0.373	0.298
0.1247...	15.501	15.330	15.286	15.228	15.170	14.902	0.599	0.428	0.384	0.326	0.268
0.0632...	29.705	29.534	29.462	29.423	29.383	29.156	0.549	0.378	0.306	0.267	0.227
0.2407...	4.898	4.781	4.723	4.699	4.655	4.458	0.440	0.323	0.265	0.241	0.197
0.1821...	6.284	6.176	6.110	6.073	6.023	5.870	0.414	0.306	0.240	0.203	0.153
0.1224...	9.006	8.892	8.860	8.799	8.773	8.656	0.350	0.236	0.204	0.143	0.117
0.0601...	17.638	17.545	17.483	17.457	17.410	17.302	0.336	0.243	0.181	0.155	0.108
0.0571...	14.796	14.689	14.659	14.619	14.613	14.537	0.259	0.152	0.122	0.082	0.076

$$\frac{C_e}{KP} = s \log \frac{P}{t} + b \ldots\ldots\ldots (30)$$

Specific values of slope s and intercept b are given in Table X, assuming that for an infinite dielectric constant the slope is zero. It is also reasonable to assume that the variation of both slopes and intercepts will be linear with $1/K$. On this assumption values of the slopes and intercepts are as given in row 3 of Table X. Then by Eq 30 and rounding the coefficients to three places:

Equal Electrodes:

$$\frac{C_e}{KP} = 0.153 \frac{1}{K} \log \frac{P}{t} - 0.225 \frac{1}{K} + 0.050 \frac{\mu\mu\text{f}}{\text{in.}} \ldots (31)$$

Unequal Electrodes:

$$\frac{C_e}{KP} = 0.214 \frac{1}{K} \log \frac{P}{t} - 0.229 \frac{1}{K} + 0.105 \frac{\mu\mu\text{f}}{\text{in.}} \ldots (32)$$

Multiplying through by K:

Equal Electrodes:

$$\frac{C_e}{P} = 0.153 \log \frac{P}{t} - 0.225 + 0.050\, K \frac{\mu\mu\text{f}}{\text{in.}} \ldots (33)$$

Unequal Electrodes:

$$\frac{C_e}{P} = 0.214 \log \frac{P}{t} - 0.229 + 0.105\, K \frac{\mu\mu\text{f}}{\text{in.}} \ldots (34)$$

The ability of these equations to give the observed values of edge capacitance was tested by calculating for all specimens the value of C_e/KP. The average errors were 5.1 per cent for equal electrodes and 2.0 per cent for unequal electrodes, with maximum errors of 21 and 6 per cent. The maximum errors occur for points that are obviously out of line. It is probable that more comprehensive observations would show some relationship between the coefficients of similar terms in Eqs 27, 33, and 34.

Ground Capacitance:

The values of ground capacitance given in the last column of Table VII indicate that this capacitance is a function of specimen thickness. Since it will also vary with the height of the specimen above the ground plane, the effect of both of these factors was studied by placing the specimens in the center of a ground plane about 18 in. square, formed by four Type 722 Precision Capacitors, and at different heights above this plane varying from $\frac{5}{8}$ to $8\frac{5}{8}$ in. The observed capacitances are given in Table XI.

The capacitances of the specimens excluding ground capacitance, as measured in the large three-terminal cell and given in column 3 of Table VII, are repeated as column 7 of Table XI. Ground capacitances, C_g, are the differences between these capacitances and those given in columns 2 to 6 and are shown in columns 8 to 12. They are plotted against thickness, t, in Fig. 10. To a good approximation, they are linear with thickness, giving the straight lines represented by the short lines at each side of the plot. These lines have nearly the same slope, although there is a tendency

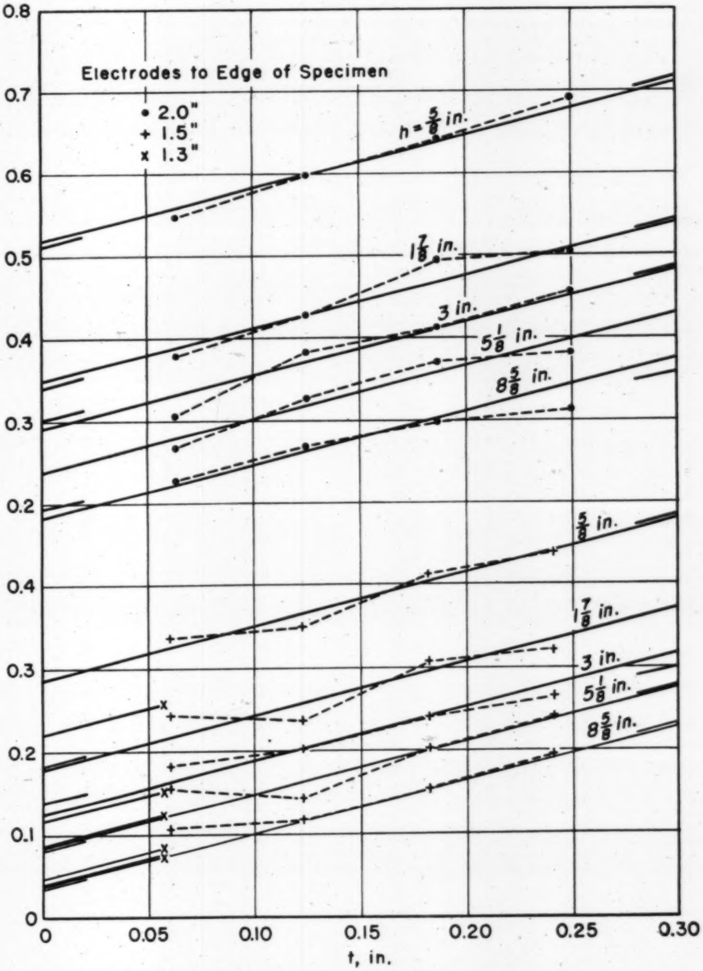

FIG. 10.—Ground Capacitance, Electrodes to Edge of Specimen.

TABLE XII.—GROUND CAPACITANCE, SLOPES AND INTERCEPTS.

h, in.	Slope		Intercept		
	d = 2.000 in.	*d* = 1.504 in.	*d* = 2.000 in.	*d* = 1.504 in.	*d* = 1.344 in.
1	*2*	*3*	*4*	*5*	*6*
0.625	0.70	0.67	0.517	0.285	0.220
1.875	0.69	0.64	0.348	0.177	0.115
3.000	0.62	0.54	0.290	0.122	0.085
5.125	0.68	0.67	0.241	0.085	0.045
8.625	0.56	0.67	0.182	0.036	0.037
Average	0.65	0.64			

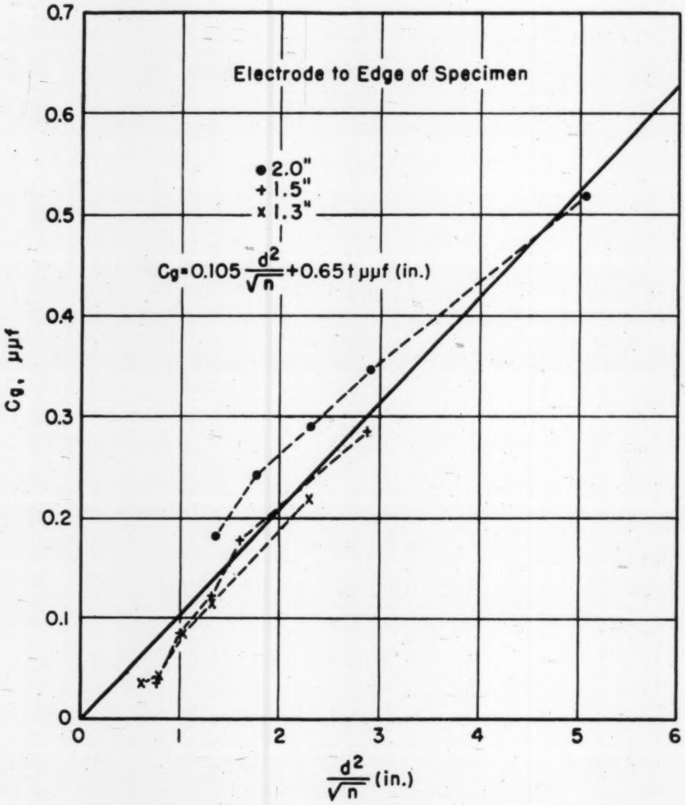

FIG. 11.—Ground Capacitance, Electrode to Edge of Specimen.

for the slope to decrease both with increasing height and decreasing diameter. Values of these slopes are given in columns 2 and 3 of Table XII.

Using an average value for slope of 0.65, the straight lines of Fig. 10 were redrawn, as shown by the full lines. Their intercepts on the capacitance axis are given in columns 4 to 6. These intercepts are functions of both diameter *d* and height *h*. Trial plots against various functions of *d* and *h* indicated that an approximately linear relation is obtained with the parameter $d^2/\sqrt{h}$, as shown in Fig. 11. This line passes through the origin and has a slope of 0.105. Hence the expression for ground capacitance is:

$$C_g = 0.105 \frac{d^2}{\sqrt{h}} + 0.65\, t \;\mu\mu\text{f(in.)} \quad .. (35)$$

Using this equation to calculate ground capacitance for the specimens, the average error is 11.3 per cent and the maximum error 32.2 per cent.

Equation 35 is, of course, entirely empirical and can hold only over a limited range of the variables involved. Ground capacitance obviously cannot become infinite for zero height, both because this capacitance is not the same as that of two parallel plates and because the edge capacitance will then be greatly changed. Further observations are needed to extend the measurements to larger specimens and to cases where the specimen extends beyond the high electrode, for which the dielectric constant of the specimen will be involved.

The ability of Eqs 27 and 35 for edge and ground capacitance to hold for a small ground plane, such as is afforded by a single Type 722 Precision Capacitor, was tested by using them to calculate the dielectric constant for the observed capacitances given in column 3 of Table VI, for which the ground electrode was 1$\frac{3}{4}$ in. above the panel of the capacitor. These values of dielectric constant are given in column 2 of Table XIII. Two other sets of observations were made for greater heights, and the results for them are given in columns 3 and 4. The true values of dielectric constant are given in column 5, taken from column 5 of Table VII. The agreement among these values is surprisingly good. The average error is 0.4 per cent and the maximum 1.3 per cent.

CONCLUSIONS

Three methods for measuring the dielectric constant of solids have been described. The two most accurate are the three-terminal guard electrode method and the two-terminal micrometer-electrode system. For both of these methods, deposited metal electrodes should be used, because the thickness of the adhesive used with foil electrodes cannot be controlled. The errors introduced by the width of the gap between the guarded and guard electrodes in the three-terminal measurements and by the irregularities in the calibration of the screw used with micrometer electrodes are generally comparable and may amount to a few tenths of 1 per cent. The guarded-electrode system is best suited to large-diameter specimens, whereas for the micrometer-electrode system, the specimens should be smaller than the electrodes until the fringing correction for specimens the same size as the electrodes has been more accurately determined.

The third method is a two-terminal measurement that requires only a grounded support for the specimen and a fine wire connector. Deposited metal electrodes should be used. The formulas for edge and ground capacitance that have been developed are good enough to keep the error less than 1.5 per cent, when the electrodes extend to the edge of the specimen. While the formulas for edge capacitance, when the specimen extends beyond either one or both electrodes, are probably equally accurate, the corresponding formulas for ground capacitance have not been developed. Such specimens can, however, be measured in a three-terminal cell or on a guard-circuit bridge whose guard terminal is grounded, thus eliminating the ground capacitance, with an error probably not greater than 1 per cent. Specimens with electrodes extending to the edge can be similarly measured.

TABLE XIII.—TWO-TERMINAL METHOD, DIELECTRIC CONSTANT.

t, in.	h = 1.75 in.	h = 2.875 in.	h = 5 in.	True
1	*2*	*3*	*4*	*5*
0.2500......	2.530	2.543	2.537	2.524
0.1864......	2.540	2.541	2.533	2.523
0.1247......	2.524	2.527	2.521	2.520
0.0632......	2.534	2.535	2.535	2.512
0.2407......	2.534	2.530	2.491	2.524
0.1821......	2.513	2.513	2.513	2.523
0.1224......	2.525	2.529	2.507	2.520
0.0601......	2.510	2.520	2.503	2.511
0.0571......	2.500	2.500	2.492	2.510

The errors just outlined refer to the capacitance measurement alone. The direct interelectrode vacuum capacitance of the specimen must be calculated in order to obtain a value of dielectric constant. Its error depends on the area and thickness of the specimen and can vary from 0.2 per cent for large thick specimens to 0.6 per cent for small thin ones. Such errors will be dominant for the two most accurate methods, but will be only moderately important for the third method. The errors in dielectric constant will then vary from 0.4 to 0.8 per cent for the first method, from 0.5 to 1.0 per cent for the second method, and from 1.6 to 2.0 per cent for the third method.

REFERENCES

(1) C. Moon and C. M. Sparks, "Standards for Low Values of Direct Capacitance," *Journal of Research*, Nat. Bureau Standards, Vol. 41, November, 1948, pp. 497–507.

(2) L. G. Hector and D. L. Woernley, "The Dielectric Constants of Eight Gases," *Physical Review*, Vol. 69, February, 1946, pp. 101–105.

(3) L. H. Ford, "The Effect of Humidity on the Calibration of Precision Air Capacitors," *Proceedings*, Inst. Electrical Engrs. (London), Vol. 96, Part III, January, 1949, pp. 13–16.

(4) L. Essen and K. D. Froome, "Dielectric Constant and Refractive Index of Air and Its Principal Constituents at 24,000 Mc/s," *Nature*, Vol. 167, March 31, 1951, p. 512.

(5) G. Birnbaum, S. J. Kryder, and H. Lyons, "Microwave Measurements of the Dielectric Properties of Gases," *Journal of Applied Physics*, Vol. 22, January, 1951, pp. 95–102.

(6) G. Birnbaum and S. K. Chatterjee, "The Dielectric Constant of Water Vapor in the Microwave Region," *Journal of Applied Physics*, Vol. 23, February, 1952, pp. 220–223.

(7) E. B. Rosa and N. E. Dorsey, "A New Determination of the Ratio of the Electromagnetic to the Electrostatic Unit of Electricity," *Bulletin*, Nat. Bureau Standards, Vol. 3, June, 1907, pp. 433–540.

(8) W. G. Amey and F. Hamburger, Jr., "A Method for Evaluating the Surface and Volume Resistance Characteristics of Solid Dielectric Materials," *Proceedings*, Am. Soc. Testing Mats., Vol. 49, p. 1079 (1949).

(9) L. Hartshorn and W. H. Ward, "The Measurement of the Permittivity and Power Factor of Dielectrics at Frequencies from 10^4 to 10^8 Cycles per Second," *Proceedings*, Inst. Electrical Engrs. (London), Vol. 79, pp. 597–609 (1936); *Proceedings*, Wireless Section, Inst. Electrical Engrs. (London), Vol. 12, March, 1937, pp. 6–18.

(10) E. B. Baker, "Automatic Measurement, Computation and Recording of Dielectric Constant and Loss Factor Against Temperature," *Review of Scientific Instruments*, Vol. 22, June, 1951, pp. 376–383.

(11) R. F. Field, "Connection Errors in Capacitance Measurements," *General Radio Experimenter*, Vol. 12, January, 1938, pp. 1–4; Vol. 21, May, 1947, pp. 1–4.

(12) A. H. Scott and H. L. Curtis, "Edge Correction in the Determination of Dielectric Constant," *Journal of Research*, Nat. Bureau Standards, Vol. 22, June, 1939, pp. 747–775.

(13) G. Kirchhoff, "On the Theory of Condensers," *Monatsber. Akad. Wiss.* (Berlin), March, 1877, p. 144; *Collected Works*, Barth (Leipzig), p. 101 (1882).

REPORT OF COMMITTEE D-10

ON

SHIPPING CONTAINERS*

Committee D-10 on Shipping Containers held two meetings during the year: at Boston, Mass., on October 23, 1953, and at Atlantic City, N. J., on April 9, 1954.

At the Spring Meeting, the following officers were elected for a two-year term:

Chairman, Gordon E. Falkenau.
Vice-Chairman, Earl R. Stivers.
Secretary, Robert F. Uncles.
Advisory Committee, A. V. Grundy and C. E. Miller.

Committee D-10 now consists of 93 members, of whom 32 are classified as producers, 36 as consumers, and 25 as general interest members.

CONTINUATION OF TENTATIVES WITHOUT REVISION

The committee recommends that the following tentatives, which have stood without revision for two or more years, be continued as tentative:

Method of Vibration Test for Shipping Containers (D 999 – 48 T), and
Methods of Testing Pallets (D 1185 – 51 T).

An extensive review of Method D 999 is currently in progress and Methods D 1185 are being continued as tentative on the basis of lack of evidence that these methods have been given sufficient field testing to prove their adequacy.

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Definition of Terms (E. J. Dahill, chairman) has under consideration revisions of the Standard Definitions of Terms Relating to Shipping Containers (D 996 – 50), and the proposed glossary of terms relating to interior packing, in the light of the many suggested changes and modifications received from the subcommittee members.

Subcommittee II on Methods of Testing (J. G. Turk, chairman),

Subcommittee IV on Performance Standards (C. R. Gustafson, chairman),

Subcommittee V on Correlation of Tests and Test Results (R. C. McKee, chairman).

These subcommittees have been merged to form a joint subcommittee charged with the task of reviewing several established test procedures to determine those factors which, as has been demonstrated, cause significant variations in results of duplicate tests conducted at several locations with all variables apparently controlled. For these studies, four task groups were organized and each is actively pursuing its separate investigation.

The Task Group on Revolving Drum Test is collecting a complete set of physical data on a number of 7-ft drums in active use in various laboratories to serve as a foundation on which to develop possible reasons for conflicting test data. The variables thus uncovered will then be checked for their individual contribution to the over-all lack of reproducibility.

The Task Group on Vibration Test also proposes to assemble a comprehensive summary of construction and instrumentation data on existing installations of vibration tables, and has formulated plans for a round-robin test to be run on the machines included in this tabulation.

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13–18, 1954.

The Task Group on Drop Test is exploring the effects of various dropping surfaces and of the orientation of the package prior to drop by means of instrumented dummy loads which permit the measurement of shock at the moment of impact.

The Task Group on Stacking is completing plans for a round-robin test on a procedure initially designed for corrugated boxes. As their work progresses, the study will be expanded to include other types of shipping containers.

Subcommittee III on Water Vapor Resistance (H. A. Bergstrom, chairman) is sponsoring a round-robin test in accordance with Methods of Test for Water Vapor Permeability of Shipping Containers (D 1008 - 51).

Subcommittee VI on Interior Packing (S. L. Swenson, chairman).—A load deflection method for determining energy absorption of cushioning materials is ready for final revision prior to presenting it to the main committee for publication as tentative. The study of a procedure for the determination of compression set and drift has also progressed, and a round-robin test produced good correlation among participating laboratories. A reissue of the bibliography and abstracts of cushioning and shock absorption studies is in preparation and will contain many new entries. A compilation of definitions of terms relating to cushioning, shock, and vibration is in process.

This report has been submitted to letter ballot of the committee, which consists of 93 members; 43 members returned their ballots, of whom 41 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

G. E. FALKENAU,
Chairman.

R. F. UNCLES,
Secretary.

REPORT OF COMMITTEE D-11

ON

RUBBER AND RUBBER-LIKE MATERIALS*

Committee D-11 on Rubber and Rubber-Like Materials, and sixteen of its subcommittees, held meetings in Washington, D. C., on February 3 to 5, 1954, during ASTM Committee Week. In addition, some of the subcommittees have held separate meetings during the year; and the SAE-ASTM Technical Committee on Automotive Rubber, with its various sections, has continued to meet on a quarterly basis.

An outstanding accomplishment of the year was the completion of a "Glossary of Terms Relating to Rubber and Rubber-Like Materials" which was published in mimeographed form in January and circulated to members of the committee and other interested parties for criticism and suggestions for improvement. The glossary has been well received and there have been numerous requests for copies, both from this country and from abroad. Subcommittee VIII, under the chairmanship of Harry L. Fisher, which has been responsible for this accomplishment, will give consideration to all suggested changes and plans eventually to submit a revision of the glossary for publication by the Society in more permanent form.

The responsibilities of Committee D-11 in representing the United States through the American Standards Association in the work of Technical Committee 45 on Rubber of the International Organization for Standardization (ISO) have grown to such an extent that it became necessary during the year to organize a special committee to handle this work. This group is under the chairmanship of R. D. Stiehler and has been designated as the American Group for ISO/TC 45 on Rubber and Rubber Products. This group includes in its membership the chairmen of the D-11 subcommittees dealing with subjects on which the ISO committee is actively working, together with other members interested in these fields. From this group, various members have been designated to serve as the United States representatives on the ISO/TC 45 Working Groups which have been organized. The American Group has accepted the chairmanship of ISO/TC Working Group on Cold Resistance, being represented thereon by Irving Kahn, U. S. Department of the Army, Office of the Chief of Ordnance. ISO/TC 45 does not plan to meet this year, but meetings of a number of the working groups will be held in London, England, June 28 to 30. 1954. The American Group will be represented at these meetings by A. E, Juve of The B. F. Goodrich Co., and L. D. Carver, Witco Chemical Co.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, Simon Collier.
Vice-Chairman, H. G. Bimmerman.
Secretary, A. W. Carpenter.

NEW TENTATIVES

Committee D-11 recommends for publication as tentative the following new specifications and methods of test as appended hereto.[1]

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13–18, 1954.

Tentative Specifications for Sheet Rubber Packing.—These specifications have been under consideration in Subcommittee VI for several years and are the first material specifications promulgated by this subcommittee. They supplement and do not conflict with any of the specifications for sheet gasketing contained in Specifications D 1170.

TABLE I.—DIMENSIONS OF TEST SPECIMENS FOR AGING TEST OF VACUUM BRAKE HOSE.

Inside Diameter of Hose, in.	Duty Type	Length of Specimen, in.	Dimension of Form, in. (See Fig. 1)			
			A	B	R	C (min)
7/32......	Light	8	4 1/2	3	1 1/2	1/2
1/4.......	Heavy	9	4 1/2	3	1 1/2	1/2
11/32.....	Light	9	4 3/4	3 1/2	1 3/4	3/4
3/8.......	Heavy	10	4 3/4	3 1/2	1 3/4	3/4
15/32.....	Light	11	5	4	2	3/4
1/2.......	Heavy	11	5	4	2	3/4
5/8.......	Heavy	12	5 1/2	4 1/2	2 1/4	7/8
3/4.......	Heavy	14	6	5	2 1/2	1
1........	Heavy	16	7	6 1/2	3 1/4	1 3/8

Tentative Methods for Evaluating Low-Temperature Characteristics of Rubber and Rubber-Like Materials by a Temperature-Retraction Procedure (TR Test).—This tentative presents in standardized form a test method which has been found very useful in evaluating the low-temperature behavior of rubber and synthetic elastomers, including the effect of crystallization.

The committee is also balloting on the following new tentatives which it proposes to refer to the Administrative Committee on Standards:[2]

Tentative Specifications for:

Polyethylene Insulated Wire and Cable,
Ozone-Resisting Butyl Rubber Insulation for Wire and Cable, and
Construction of Rubber Insulated Wire and Cable.

REVISION OF TENTATIVES

The committee recommends that nineteen of the present tentatives be revised as indicated and continued as tentative:

Tentative Methods of Sample Preparation for Physical Testing of Rubber Products (**D 15 - 52 T**).[3]

Section 1(a).—Revise the Scope to read as follows:

> 1. These methods apply to the procedures for the compounding and mixing of certain basic standard rubber compound formulations, utilizing standard ingredients together with recommended times and temperatures of cure. They may also be used to prepare mixes of the standard compounds in which one or more of the ingredients is non-standard or in which all ingredients are non-standard. They may also be used when it is desired to substitute a different material for one of the standard materials. However, such substitutions may require changes in the standard mixing and curing procedures.

This revision clarifies the manner in which the standard compound formulations are used.

Tentative Methods for Chemical Analysis of Rubber Products (**D 297 - 50 T**).[3]—These revisions, appended hereto,[4] include changes in the methods of separating and titrating zinc from a rubber ash solution prior to the determination of calcium and magnesium. They also include improved methods for the determination of small amounts of copper and manganese in rubber. The recommendation is based on extensive studies carried out by Subcommittee XI which have shown that the changes improve both the accuracy and the ease of manipulation of the determinations.

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[1] The new tentatives were accepted by the Society and appear in the 1954 Supplement to Book of ASTM Standards, Part 6.

[2] See Editorial Note, p. 489.

[3] 1952 Book of ASTM Standards, Part 6.

[4] The revised tentative appears in the 1954 Supplement to Book of ASTM Standards, Part 6. See also Editorial Note, p. 489.

Tentative Methods of Testing Automotive Air Brake and Vacuum Brake Hose (**D 622 – 48 T**).[3]—The following revisions have been developed by Technical Committee A to provide for testing the light-duty type of vacuum brake hose:

TABLE II.—DIMENSIONS OF BEND TEST SPECIMEN OF VACUUM BRAKE HOSE.

Inside Diameter of Hose, in.	Length of Specimen, in.	
	Heavy Duty	Light Duty
7/32	..	7
1/4	8	..
11/32	..	11
3/8	12	..
15/32	..	14
1/2	16	..
5/8	22	..
3/4	28	..
1	36	..

TABLE III.—DIMENSIONS OF TEST SPECIMEN AND FEELER GAGE FOR DEFORMATION TEST OF VACUUM BRAKE HOSE.

Inside Diameter of Hose, in.	Duty Type	Specimen Dimensions, in. (See Fig. 5)		Feeler Gage Dimensions, in.	
		D	*L*	Width	Thickness
7/32	Light	3/64	1	1/8	3/64
1/4	Heavy	1/16	1	1/8	1/16
11/32	Light	5/64	1	3/16	5/64
3/8	Heavy	3/32	1	3/16	3/32
15/32	Light	5/64	1	1/4	5/64
1/2	Heavy	1/8	1	1/4	1/8
5/8	Heavy	5/32	1	1/4	5/32
3/4	Heavy	3/16	1	1/4	3/16
1	Heavy	1/4	1	1/4	1/4

Table I.—Revise the requirements for vacuum brake hose to read as shown in the accompanying Table I. No change is recommended in the requirements for air brake hose specimens.

Table II.—Change to read as shown in the accompanying Table II.

Table III.—Change to read as shown in the accompanying Table III.

Section 13(c).—Change the last sentence to read as follows: "The specimen shall be considered to have failed to meet the test unless the load is less than that specified on the first application and unless the load is greater than that specified on the fifth application."

Section 14(a).—Change "di-isobutylene" in the first sentence, third sentence, and fourth sentence to "*iso*octane." Add a reference number after the word *iso*octane with reference to the following footnote: "*Iso*octane shall conform to the requirements of Reference Fuel A of the Tentative Methods of Test for Changes in Properties of Rubber and Rubber-Like Materials in Liquids (ASTM Designation: D 471)."

New Section.—Add as new Section 17 the following test for increase in volume, and renumber Section 17 as 18.

> 17. *Increase in Volume.*—The increase in volume of the cover shall be determined in accordance with Section 24 of the Tentative Methods of Testing Rubber Hose (ASTM Designation: D 380), except that *iso*octane (Reference Fuel A, ASTM Method D 471) shall be used as the immersion medium. The test specimen shall be prepared from the cover as described in Section 9(*a*) of Method D 380 and shall be as near the size specified in Section 24(*a*) of Method D 380 as can be obtained from the hose being tested.

Tentative Specifications for Rubber and Synthetic Rubber Compounds for Automotive and Aeronautical Applications (**D 735 – 52a T**).[3]

Section 2(c).—Change the definition of Suffix L in the suffix tabulation, to read as follows:

> L . . . Water absorption test required. Values to be agreed upon between purchaser and supplier, except for Class TA compounds (Table V).

Replace Suffix K by two Suffixes, K_1 and K_2, defined as follows:

> K_1 . . . Adhesion test required, elastomer to metal, bond made during vulcanization process.**

K_2... Adhesion test required, cemented bond, made after vulcanization process.**

Table I—Type R Compounds, Non-Oil Resistant.—In the column headed Ultimate Elongation, min, per cent, change the values for the 80 hardness grades as follows:

R805........	remains as 100 per cent
R810........	150 per cent, change to 100 per cent
R815........	200 per cent, change to 150 per cent
R820........	250 per cent, change to 200 per cent
R825........	300 per cent, change to 200 per cent

Table V, Suffix L, Water Absorption.—Change the aging period from "168 hr at 158 F" to "70 hr at the boiling temperature of water"; also change the limits for volume change throughout from "10 per cent max" to "5 per cent max."

Section 6(f), Test Liquids.—For Suffix requirement L, delete the present paragraph and reword as follows: "For suffix requirement L, distilled water shall be used. Increase in volume shall be determined using the procedure described under water displacement method for water insoluble liquids and mixed liquids, of ASTM Method D 471, except that the acetone dip shall be omitted. Change in durometer hardness shall be determined using the procedure described under 'Changes in tensile strength, elongation, and durometer hardness' of Method D 471. The cooling period in distilled water shall be 30 min and the acetone dip shall be omitted."

Tentative Method of Test for Low-Temperature Brittleness of Rubber and Rubber-Like Materials (**D 736 – 46 T**).[3,4]

Section 2(a).—Delete the last sentence of this section and add the following note:

NOTE.—Temperatures of −40 F and −65 F are commonly used.

Tentative Method of Measuring Low-Temperature Stiffening of Rubber and Rubber-Like Materials by the Gehman Torsional Apparatus (**D 1053 – 52 T**).[3]

Section 2.—Add the following note at the end of the section:

NOTE.—The Gehman torsional apparatus may be used in liquid coolants provided the following conditions are met: (*a*) The coolant shall be liquid over the desired temperature range. (*b*) It shall be shown that the liquid does not soften or otherwise affect the test specimens. (*c*) The temperature of the coolant shall be uniform within ±1 C in all portions of the medium. Means shall be provided for maintaining controlled coolant temperatures for periods of at least 10 min.

Section 5.—Add the following note at the end of the section:

NOTE.—The long-term cold hardening test may be performed in a suitable low-temperature cabinet or cold room. The entire apparatus, with the exception of the millivoltmeter and electric timer, shall be placed in the cabinet or room, and the test made while still in the cabinet.

These notes permit testing in liquid media and also in a cold box.

Tentative Specifications and Methods of Test for Latex Foam Rubbers (**D 1055 – 53 T**).[5]—The committee recommends the revision of these specifications in order to make the following changes: In Section 4 the changes will make the text consistent with the Tentative Specifications for Rubber and Synthetic Rubber Compounds for Automotive and Aeronautical Applications (ASTM Designation: D 735). In Table I the RMA Designation has been changed in order to correspond with the present RMA Designations. In Section 14 (*b*) the reference to a stem weight has been deleted since 25 g, as now required, is heavy enough to compress the softer foams. The sectional committee which studied this matter stated that it could find no better method of describing the test than the Method D 1055, which also corresponds to the RMA recommended method. The new method in Section 30 corresponds to the method shown in the RMA Buyers Guide.

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[5] 1953 Supplement to Book of ASTM Standards, Part 6.

Section 4: Suffix Letter.—Change "F" to "F_1." Add new suffix letter "F_2" defined as follows: "F_2—Low temperature test at −65 F required."

Table I.—Change "Suffix F" to read "Suffix F_1." Add a new grade R 20½ under Latex Foam (Cored), change the figures under RMA Designation to correspond with the present RMA Designations, and add three new grades under Latex Foam Rubbers (Uncored), to read as shown in the accompanying Table IV. Retain all of the present grades without change otherwise.

TABLE IV.—PHYSICAL REQUIREMENTS OF LATEX FOAM RUBBERS.

Basic Requirements					Requirements Added by Suffix Letters	
					Suffix F_1	Suffix H
Grade Number	RMA[a] Designation	Indentation of 50 sq in, 25 per cent Deflection (Limits), lb	Air Oven Aged 22 hr at 212 F Change from Original Load-Deflection or Indentation Value (Limits), per cent	Compression Set, 22 hr at 158 F, 50 per cent Deflection, max, per cent	Low Temperature Test, Change from Original Deflection, max, per cent	Flexing Test, Compression Set, max, per cent
Latex Foam Rubbers (Cored)						
R 20½	½	6½ ± 3½	20	20	75	20
Latex Foam Rubbers (Uncored)						
	X Firm					
R 36	XX Firm	100 ±15	20	20	75	
R 37	XXX Firm	132½±17½	20	20	75	
R 38	XXXX Firm	175 ±25	20	20	75	

Section 7.—Reletter as Paragraph (*a*) and add a new Paragraph (*b*) as follows:

(*b*) The latex foam specimen shall show no cracking at the folded edge when subjected to the static fatigue test.

Section 14 (*b*).—Change the first sentence of this paragraph to read as follows: "Thicknesses up to and including 1 in. shall be measured using a dial-type gage having a foot $1\frac{1}{4}$ in. in diameter, taking care not to compress the sample."

Section 28.—Change the last sentence to read as follows: ". . . . and the deflection recorded 30 sec later."

Section 30.—Add a new test method covering static fatigue to read as follows:

Static Fatigue Test

30. *Procedure:* (*a*) *Slab Stock.*—A specimen of latex foam 4 by 9 in. shall be bent parallel to the 4-in. dimension to an angle of 180 deg between two compression plates and placed in a Geer Oven at 158 F for 22 hr. The opening between the two plates should be equal to twice the thickness of the unfolded specimen. The folded edge of the specimen should not extend beyond the edge of the compression plates.

(*b*) *Cored Stock.*—This specimen shall be tested as in Paragraph (*a*), except that the specimen shall be 4 in. wide and the length shall be approximately three times the thickness. The skin side, if present, shall be folded out for testing.

Tentative Specifications and Methods of Test for Sponge and Expanded Cellular Rubber Products (**D 1056 – 53 T**).[5]—The committee recommends the revision of these specifications in order to make the following changes: In Section 5 the changes will make the text consistent with the Tentative Specifications for Rubber and Synthetic Rubber Compounds for Automotive and Aeronautical Applications (ASTM Designation: D 735). The change in Table I is in order since the cellular rubber deflects less under the same load as the temperature is reduced. The change in Section 31 was made since it was not practical to record the deflection immediately, as previously required. The change should not materially affect the results obtained under this test.

Section 5: Suffix Letter.—Change "F" to "F_1."Add new suffix letter "F_2" defined as follows: "F_2—Low temperature test at −65 F required."

Table I.—Change Suffix "F" to "F_1." Change the heading over the Suffix F_1 column to read as follows: "Low Temperature Test, Change from Original Deflection, max, per cent."

Table II.—Make the same changes in Table II as in Table I, except under the Oil Aged column change the heading to read as follows: "Oil Aged 22 hr. at 158 F, Change in Volume in ASTM Oil No. 3 (Limits)."

Table III.—Make the same changes as in Table II.

Table IV.—Change the Aniline Point to read "69.5 ± 1 C" instead of "69.5 ± 1.5 C."

Section 31.—Change the last sentence to read as follows: ". . . . and the deflection recorded 30 sec later."

Tentative Specifications and Methods of Test for Concentrated, Ammonia Preserved, Creamed and Centrifuged Natural Rubber Latex (**D 1076 - 52 T**).[3]—Recommended changes in sampling and the mechanical stability test are the result of extensive negotiations between Subcommittee VII and the ISO/TC 45 Group working on latex. The addition of the methods for determination of density is of considerable importance commercially and will provide much needed standard methods. This revision is appended hereto.[4]

Tentative Specifications for Non-Metallic Gasket Materials for General Automotive and Aeronautical Purposes (**D 1170 - 51 T**).[3,4]

Table II, Type 1, Natural and/or Synthetic Rubber and Asbestos (Compressed).—Make the following changes:

Grades G-1222-2, G-1222-3, and G-1222-4—change volume change limits after aging in ASTM No. 1 Oil from "−5 to + 5" per cent to "−10 to +10 per cent."

Grades G-1223-2, G-1223-3, and G-1223-4—change volume change limits after aging in ASTM No. 3 Oil "+25 to 60 per cent" to "+15 to 50 per cent."

Grade G-1211-3—delete volume change limits of "−5 to +5 per cent" after immersion in ASTM Reference Fuel No. 1.

Grade G-1221-3—insert volume change limits of "−5 to +5 per cent" after immersion in ASTM Reference Fuel No. 1, 22 hr at 70 to 85 F.

Grade G-1423-3—change tensile strength from "500 psi" to "1000 psi."

Table III, Type 2, Cork Compositions.—Make the following changes:

Grades G-2211, G-2212, G-2213 and G-2214—insert under Flotation Tests, 3 hr in boiling water, the words "no disintegration."

Grades G-2111 and G-2211—change compression from "40 to 60 per cent" to "30 to 50 per cent."

Grades G-2112 and G-2212—change compression from "30 to 50 per cent" to "20 to 40 per cent."

Grades G-2113 and G-2213—change compression from "25 to 40 per cent" to "15 to 30 per cent."

Grades G-2114 and G-2214—change compression from "15 to 30 per cent" to "10 to 25 per cent."

Table IV, Type 3, Treated and Untreated Papers.—Make the following changes:

Grades G-3261 and G-3262—reduce compression strength as follows:
    Original from "22,500 psi" to "20,000 psi."
    Aged 70 hr at 250 F. in ASTM No. 1 Oil from "20,000 psi" to "18,000 psi."

Grades G-3211, G-3212 and G-3213—change recovery from "50 per cent" to "40 per cent."

Grade G-3221—reduce tensile strength from

"2000 psi" to "1500 psi." Also, change compressibility from "30 to 45 per cent" to "25 to 40 per cent" and recovery from "50 per cent" to "40 per cent." Change Mullen bursting strength from "45 psi" to "40 psi."

Change Footnote *a* describing thickness tolerances to read as follows:

[a] Thickness Tolerances: 1/64 in. and under, ±0.0035 in.; over 1/64 to 1/16 in., ±0.005 in.; over 1/16 to 3/32 in., ±0.008 in.; over 3/32 in., ±0.016 in.

The committee is also balloting on revisions of the following tentatives which it proposes to refer to the Administrative Committee on Standards:[2]

Tentative Specifications for:

Insulated Wire and Cable: Class AO, 30 Per Cent Hevea Rubber Compound (D 27 - 52 T),
Insulated Wire and Cable: Performance Rubber Compound (D 353 - 52 T),
Insulated Wire and Cable: Heat-Resistant Rubber Compound (D 469 - 52 T),
Insulated Wire and Cable: Ozone-Resistant Type Insulation (D 574 - 46 T),
GR-M Polychloroprene Sheath Compound for Electrical Insulated Cords and Cables (D 752 - 49 T),
Insulated Wire and Cable: Heat-Resisting Synthetic Rubber Compound (D 754 - 52 T),
Insulated Wire and Cable: Performance Synthetic Rubber Compound (D 755 - 52 T), and
GR-S Synthetic Rubber Sheath Compound for Electrical Insulated Cords and Cables (D 866 - 46 T).

Tentative Methods of:

Testing Rubber Insulated Wire and Cable (D 470 - 52 T).

REVISION OF STANDARDS AND REVERSION TO TENTATIVE

The committee is balloting on revisions of the following standards, including their reversion to tentative, which it proposes to refer to the Administrative Committee on Standards:[2]

Standard Specifications for:

Rubber Sheath Compound for Electrical Insulated Cords and Cables (D 532 - 49), and
GR-M Polychloroprene Sheath Compound for Electrical Insulated Cords and Cables Where Extreme Abrasion Resistance is Not Required (D 753 - 49).

REVISIONS OF STANDARDS, IMMEDIATE ADOPTION

The committee recommends for immediate adoption the following revisions of the Standard Methods of Test for Tear Resistance of Vulcanized Rubber (**D 624 - 48**)[3] and accordingly asks for the necessary nine-tenths affirmative vote at the Annual Meeting in order that these revisions may be referred to letter ballot of the Society:

Section 6(b).—Add the following sentence to this section: "One measurement shall be made at the apex of the slit or the 90-deg angle as applicable."

Section 9.—In line 4, delete the word "average" before the word "thickness."

These changes are recommended for the purpose of specifying definitely the procedure for measuring thickness of the test specimens in the tear test.

EDITORIAL CHANGE IN TENTATIVE

Tentative Methods of Testing Adhesives for Brake Lining and Other Friction Materials (**D 1205 - 53 T**).[5]

Section 16.—Add the following note at the end of this section:

NOTE.—Percentage of flow is influenced by composition of the material, thickness of the film, and the rate of temperature rise of the oven.

TENTATIVES CONTINUED WITHOUT REVISION

The committee recommends that all tentatives under its jurisdiction, other than those mentioned in this report, be continued as tentative. Most of these are being reviewed by the various subcommittees, and the results of this work will be presented to the Society as it is completed.

The recommendations appearing in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[6]

ACTIVITIES OF SUBCOMMITTEES

The committee records with sorrow its loss in the sudden death of L. E. Cheyney, Minnesota Mining and Mfg. Co., chairman of Subcommittee XX on Adhesion Tests. The work which Mr. Cheyney had carried on so faithfully has been continued under H. H. Irvin, Marbon Corp., who was appointed chairman to succeed him. A. E. Williams, B. F. Goodrich Co., has been appointed chairman of Subcommittee I on Mechanical Rubber Hose. J. A. Williams, Haartz-Mason, Inc., has succeeded S. H. Tinsley, R. T. Vanderbilt Co., Inc., as chairman of Subcommittee XXIV on Rubber-Coated Fabrics following Mr. Tinsley's resignation.

The various subcommittees of Committee D-11 have been very active during the year and are working on many interesting projects, only a few of which can be mentioned here.

Subcommittee X on Physical Tests (L. V. Cooper, chairman) is engaged in a study of methods of measuring mill roll and stock temperatures during the processing of experimental rubber batches. Better control of these temperatures is considered essential for improving the reproducibility in preparation of standard compounds and experimental batches for testing. This subcommittee is also studying methods of buffing rubber specimens in order to improve accuracy and reproducibility in testing.

Subcommittee XI on Chemical Analysis (W. P. Tyler, chairman) is actively working on methods of analysis for carbon black in rubber compound. The subcommittee has selected two methods which seem better than the present standard and have planned a cooperative test program investigating these methods.

Subcommittee XV on Life Tests (G. C. Maassen, chairman) expects in the near future to present revisions of the Oxygen-Pressure Aging Method (D 572), and the Test Tube Aging Method (D 865), in order to permit the use of metal heating media in place of the present water, oil, or air media. The subcommittee recognizes that the newer types of aging test equipment utilizing aluminum block heating are proving very effective and have distinct advantages in many cases.

Subcommittee XIX (W. N. Keen, chairman) has in progress an extensive revision of Methods D 471, tests for changes in properties of rubber and rubber-like materials immersed in liquids. This revision will bring these methods up-to-date and are expected to be completed and submitted to the Society in the near future through the Administrative Committee on Standards.[2]

A number of the other subcommittees have cooperative test programs in progress and will report the results as the data are accumulated.

This report has been submitted to letter ballot of the committee, which consists of 216 members; 117 members returned their ballots, of whom 104 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

S. COLLIER,
Chairman.

ARTHUR W. CARPENTER,
Secretary.

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[6] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee D-11 presented to the Society through the Administrative Committee on Standards the following recommendations:

Tentative Specification for:

Polyethylene Insulated Wire and Cable (D 1351 – 54 T),
Ozone-Resisting Butyl Rubber Insulation for Wire and Cable (D 1352 – 54 T), and
Construction of Rubber Insulated Wire and Cable (D 1350 – 54 T).

Tentative Recommended Practice for:

Standard Test Temperatures for Rubber and Rubber-like Materials (D 1349 – 54 T).

Revision of Tentative Specifications for:

Insulated Wire and Cable: Class AO, 30 per cent Hevea Rubber Compound (D 27 – 52 T),
Insulated Wire and Cable: Performance Rubber Compound (D 353 – 52 T),
Insulated Wire and Cable: Heat-Resisting Rubber Compound (D 469 – 52 T),
Insulated Wire and Cable: Ozone-Resisting Type Insulation (D 574 – 46 T),
GR-M Polychloroprene Sheath Compound for Electrical Insulated Cords and Cables (D 752 – 49 T),
Insulated Wire and Cable: Heat-Resisting Synthetic Rubber Compound (D 754 – 52 T),
Insulated Wire and Cable: Performance Synthetic Rubber Compound (D 755 – 52 T),
GR-S Synthetic Rubber Sheath Compound for Electrical Insulated Cords and Cables (D 866 – 46 T), and
Nonmetallic Gasket Materials for General Automotive Purposes (D 1170 – 54 T).

Revision of Tentative Method of:

Testing Rubber Insulated Wire and Cable (D 470 – 46 T),
Chemical Analysis of Rubber Products (D 297 – 54 T),
Test for Changes in Properties of Rubber and Rubber-like Materials in Liquids (D 471 – 52 T),
Test for Low-Temperature Brittleness of Rubber and Rubber-like Materials (D 736 – 54 T), and
Heat Aging of Vulcanized Natural or Synthetic Rubber by Test Tube Method (D 865 – 53 T).

Revision of Tentative Specifications and Methods of Test for:

Concentrated, Ammonia Preserved, Creamed and Centrifuged Natural Rubber Latex (D 1076 – 54 T).

Revision and Reversion to Tentative of Standard Specifications for:

Rubber Sheath Compound for Electrical Insulated Cords and Cables (D 532 – 49), and
GR-M Polychloroprene Sheath Compound for Electrical Insulated Cords and Cables Where Extreme Abrasion Resistance Is Not Required (D 753 – 49).

These recommendations were accepted by the Standards Committee on January 10, 1955, and the new and revised tentatives appear in the 1954 Supplement to Book of ASTM Standards, Part 6, and also in the January, 1955, Compilation of ASTM Standards on Rubber and Rubber-like Materials.

REPORT OF COMMITTEE D-12

ON

SOAPS AND OTHER DETERGENTS*

Committee D-12 on Soaps and Other Detergents held one meeting during the year: on March 22 and 23, 1954, in New York City, N. Y. At this meeting the following officers were elected for the ensuing term of two years:

Chairman, J. C. Harris.

Vice-Chairman, Frederick Krassner.

Secretary, H. R. Suter.

During the year C. F. Jelinek was appointed chairman of Subcommittee G-2 on Nomenclature and Definitions, replacing William G. Morse who has retired. William Stericker has been appointed chairman of Subcommittee S-4 on Specifications for Alkaline Detergents, replacing M. F. Graham who resigned this position.

A new Subcommittee T-7 on Sampling and Interpretation of Data was organized with C. H. Fuchs as chairman.

At the present time the committee consists of 119 members, of whom 59 are classified as producers, 35 as consumers, and 25 as general interest members, with 5 consulting members.

NEW TENTATIVE

The committee recommends that the Methods of Test for Surface and Interfacial Tension of Solutions of Surface-Active Agents, published as information with the 1952 report of the committee,[1] be accepted for publication as tentative.

REVISION OF TENTATIVE

The committee recommends that the Tentative Method of Test for pH of Aqueous Solutions of Soaps and Detergents (**D 1172 - 51 T**)[2] be revised as appended hereto.[3]

REVISION OF STANDARDS, IMMEDIATE ADOPTION

The committee recommends for immediate adoption the following revisions of four standards and requests the necessary nine-tenths affirmative vote at the Annual Meeting in order that these recommendations may be referred to letter ballot of the Society:

Standard Methods of Sampling and Chemical Analysis of Soaps and Soap Products (**D 460 - 46**):[2]

Section 34.—In lines 11 and 12, change the sentence which now reads "Wash the acids in this manner three times" to read: "Repeat the washing of the acids in this manner until the final washing is neutral to methyl orange indicator (usually 3 to 6 washings)."

Standard Methods of Sampling and Chemical Analysis of Alkaline Detergents (**D 501 - 49**):[2]

Sections 18 to 24.—Change the subtitle "Sodium Metasilicate and Sodium Sesquisilicate" preceding Sections 18 to 24 to read "Sodium Metasilicate,

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13-18, 1954.

[1] *Proceedings*, Am. Soc. Testing Mats., Vol. 52, p. 447.

[2] 1952 Book of ASTM Standards, Part 7.

[3] The revised method was accepted by the Society and appears in the 1954 Supplement to Book of ASTM Standards, Part 7.

Sodium Sesquisilicate, and Sodium Orthosilicate."

Section 18.—Change the first sentence to read as follows:

18. Sodium metasilicate, sodium sesquisilicate, and sodium orthosilicate shall be sampled by removing portions from various parts of the container.

New Section.—Add a new Section 25 as follows, and renumber the present Section 25 and succeeding sections accordingly:

25. *Sodium Orthosilicate.*—The results of analysis of sodium orthosilicate shall be expressed in terms of Na_2O, SiO_2, and matter insoluble in water.

Standard Definitions of Terms Relating to Soaps and Other Detergents (**D 459 – 52**):[2]

Under the heading "Detergent" change the term "alkaline detergent" to read "inorganic alkaline detergent."

EDITORIAL CHANGE

The committee recommends the following editorial changes to correct typographical errors in the Standard Specifications for Sodium Bicarbonate (**D 928 – 52**):[2]

Section 3.—Change the requirements for chemical composition to read as follows:

Na_2CO_3, max., per cent	0.4
$NaHCO_3$, min., per cent	99.6
Matter insoluble in water, max., per cent	0.1

Section 5.—In line 4, change "Special" to "Alkaline."

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[4]

ACTIVITIES OF SUBCOMMITTEES

Subcommittee T-1 on Soap Analysis (E. W. Blank, chairman) which functions jointly with a committee of the American Oil Chemists' Society, is currently concerned with development of analytical methods for the determination of sodium chloride, copper, and P_2O_5 in soaps and synthetic detergents.

Subcommittee T-2 on Analysis of Synthetic Detergents (R. Bernstein, chairman).—During the year a special technical publication prepared by this subcommittee entitled "Bibliographical Abstracts of Methods for Analysis of Synthetic Detergents" was issued by the Society.[5] The subcommittee intends to revise the bibliography approximately every two years. Task groups are currently working on analytical methods based on infrared spectroscopy and on methods for determination of active agent.

Subcommittee T-3 on Analysis of Dry-Cleaning Materials (G. P. Fulton, chairman) is engaged in drawing up methods for the determination of moisture, nonvolatile matter, and flash points of dry-cleaning detergents.

Subcommittee T-4 on Analysis of Alkaline Detergents (W. H. Koch, chairman) has completed methods of analysis for sodium orthosilicate and is investigating methods of analysis for sodium polyphosphates.

Subcommittee T-5 on Physical Testing (A. M. Schwartz, chairman) is engaged in the study of methods for measurement of redeposition of soil on cotton fabrics. A comprehensive bibliography is in preparation. Task groups are working on standardization of wetting and rewetting tests, reflectance measurements on fabrics, and measurement of the effect of brightening agents on textiles.

Subcommittee T-6 on Analysis of Metal Cleaners (J. C. Harris, chairman) is continuing its work on the preparation of a laboratory guide for the evaluation of metal cleaners and its study of application methods of metal cleaners in the automobile industry. A study of corrosion tests for detergent materials on vitreous enamel surfaces is to be undertaken.

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[4] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

[5] Issued as separate publication *ASTM STP No. 150.*

Subcommittee T-7 on Sampling and Interpretation of Data (C. H. Fuchs, chairman).—This newly organized committee has as its first projects statistical studies of wetting tests and redeposition methods, both in cooperation with Subcommittee T-5. The committee intends to function in recommending design of cooperative experiments and assisting in interpretation of results.

Subcommittee S-1 on Specifications for Soaps (Frederick Krassner, chairman) is working on revision of Standard Specifications for Milled Toilet Soap (D 455 – 48).

Subcommittee S-4 on Specifications for Alkaline Detergents (William Stericker, chairman) is starting work on a modification of the existing specification for sodium carbonate, and is preparing tentative specifications for sodium orthosilicate, anhydrous sodium metasilicate, and anhydrous trisodium phosphate.

Subcommittee G-2 on Nomenclature and Definitions (C. F. Jelinek, chairman) is preparing definitions for brightening agents and is attempting to resolve differences in definitions existing between English and American practice.

Subcommittee G-5 on Program Planning (R. B. Mitchell, chairman) prepared the program for the annual meeting of Committee D-12 which, in addition to regular committee activities, included presentation of the following technical papers:

"Need for a Standardized Procedure for Measuring Reflectance of Detergency Fabrics," by H. Paitchel, J. A. Woodhead, and R. B. Diaz, Colgate-Palmolive Co.[6]

"Silicates as Corrosion Inhibitors in Synthetic Detergent Mixtures," by Raymond Getty, Newton W. McCready, and William Stericker.[7]

"Turbidometric and Viscometric Measurements on Aqueous Solutions of a Nonionic Detergent," by Lawrence M. Kushner and Willard D. Hubbard.

"The Kerosine-Viewer Test in Metal Cleaning," by E. R. Holman and Francis E. Clark, Turco Products, Inc.

This report has been submitted to letter ballot of the committee, which consists of 119 members; 78 members returned their ballots, of whom 64 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

J. C. HARRIS,
Chairman.

H. R. SUTER,
Secretary.

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[6] ASTM BULLETIN, No. 202, December, 1954, p. 56 (TP242).

[7] To be published in ASTM BULLETIN.

REPORT OF COMMITTEE D-13

ON

TEXTILE MATERIALS*

Committee D-13 on Textile Materials held two meetings during the year: on October 14 to 16, 1953, in New York, N. Y., and on March 16 to 19, 1954, also in New York.

The fall meeting included a Symposium on Design of Experiments with papers by L. I. Horner, Celanese Corporation of America; J. W. Tukey, Princeton University; and W. J. Youden, National Bureau of Standards. At the spring meeting, an extra day was devoted to meetings of task groups, enabling some 30 groups to carry on their work in addition to meetings of 18 subcommittees.

The Harold DeWitt Smith Memorial Medal for 1954 was presented to A. Griffin Ashcroft.

The following changes in subcommittee organization and officers were made during the year: Section VI on Narrow Fabrics of Subcommittee A-1 has been combined with Section III on Cotton Woven Fabrics. The new Subcommittee A-6 on Warp Knit Fabrics was organized with C. A. Baker and R. L. Stimmel, as chairman and secretary, respectively.

The following changes in subcommittee officers were approved by the Advisory Committee during the year:

J. K. Frederick, Jr., and J. H. Baldt, appointed as chairman and secretary, respectively, of A-2, Section II; J. M. Gould, vice H. C. Haller as secretary of A-3, Section I; F. J. O'Neil, vice F. W. Noechel, as chairman of A-3, Section III; P. O. Nicodemus, vice F. S. Mapes, as chairman of A-4; R. H. Seeds and J. B. Curley, vice F. C. Kennedy and E. M. Simon, Jr., as chairman and secretary respectively of A-9; J. K. Sumner, vice G. B. Harvey, as chairman of A-10 and of A-10, Section II; C. B. Crandall, vice C. A. Farley, as secretary of B-5.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, W. D. Appel.
First Vice-Chairman, R. T. Kropf.
Second Vice-Chairman, C. W. Dorn.
Secretary, W. H. Whitcomb.

RECOMMENDATIONS AFFECTING STANDARDS

Committee D-13 is presenting for publication 7 new tentatives and is recommending the revision of 6 tentatives, tentative revision of 4 standards, adoption as standard of several definitions and 14 tentatives, and withdrawal of an appendix to a tentative.

The standards and tentatives affected, together with revisions recommended, are listed in detail in the Appendix.[1]

All other tentatives not specifically referred to are being actively studied by the respective sponsoring subcommittees.

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13–18, 1954.

[1] See p. 496.

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[2]

ACTIVITIES OF SUBCOMMITTEES

Subcommittee A-1 on Cotton and Its Products (B. L. Whittier, chairman):

Section I on Cotton (G. S. Buck, Jr., chairman) is continuing the development of separate standard methods of test for each of the various properties of cotton.

Section II on Cotton Yarns and Threads (W. R. Marsden, chairman) is continuing its study of methods of twist determination. Inspection of the appearance standards is being continued for which there is a continuing demand particularly in Europe. The setting up of new standards is being considered.

Subcommittee A-2 on Man-Made Organic-Base Fibers and Their Products (J. K. Frederick, Jr., chairman):

Section I on Spun and Continuous Filament Yarns (J. K. Frederick, Jr., chairman) is continuing its study of the regain bases for testing, and is proposing a new tentative which is a consolidation of Methods D 258, D 507, and D 508 on yarns from man-made and mixed fibers.

Section II on Fabrics (J. K. Frederick, Jr., chairman) is proposing a new test method for yarn distortion in woven fabric, and a revision of D 416 – 39, Maximum Residual Shrinkage of Silk, Rayon, and Acetate Woven Fabrics. A seam strength test is under consideration.

Subcommittee A-3 on Wool and Its Products (Werner von Bergen, chairman):

Section I on Wool (O. P. Beckwith, chairman) is continuing its work on testing wool for fineness, moisture, and fiber length.

Section III on Woolen and Worsted Yarns (F. J. O'Neil, chairman) is studying moisture regain, yarn number tolerances, and yarn evenness.

Section V on Woolen and Worsted Fabrics (E. M. Lynch, Jr., chairman) is studying wrinkle recovery and thickness.

Subcommittee A-4 on Asbestos and Its Textile Products (P. O. Nicodemus, chairman) is continuing its study of analysis of asbestos materials with particular reference to iron, cotton, and fiberglass.

Subcommittee A-5 on Bast and Leaf Fibers and Their Products (S. J. Hayes, chairman) is continuing its study of acceptance testing. It is planned to hold a joint papers session on this subject with Subcommittee B-5 in October, 1954.

Subcommittee A-6 on Warp Knit Fabrics (C. A. Baker, chairman) is studying strength testing, dimensional stability, yield, and grading of warp knit fabrics.

Subcommittee A-7 on Ultimate Consumer Textile Products (A. F. Tesi, chairman) is continuing its studies of the test methods for pilling, elastic fabrics, and slide fasteners.

Subcommittee A-10 on Non-Woven Fabrics (J. K. Sumner, chairman):

Section I on Felt (R. H. Carter, chairman) is continuing its study of stiffness of felts and mildew resistance and is considering heat stability and wool content.

Subcommittee A-11 on Pile Fabrics (T. F. Jacoby, chairman) is continuing its work on fire resistance, tests for tufted pile floor coverings, service properties of non-wool pile fabrics, and colorfastness to light and wet cleaning.

Subcommittee B-1 on Test Methods (W. M. Scott, chairman) is continuing its study of vibroscope methods for fiber weight per unit length, fiber crimp, yarn twist, stiffness, knit fabrics, analysis of fiber mixtures, testing machines, mercerization of cotton, abrasion re-

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[2] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

sistance, shirt wear test, and evenness of yarn.

Subcommittee B-2 on Nomenclature and Definitions (A. G. Scroggie, chairman) is continuing its work on developing tentative and standard definitions. A glossary of visual defects in woven and knitted fabrics is being developed.

Subcommittee B-5 on Sampling, Presentation, and Interpretation of Data (J. C. Hintermaier, chairman) is preparing a Manual of Statistical Methods for Textile Technologists.

This report has been submitted to letter ballot of the committee, which consists of 345 members; 173 returned their ballots, of whom 173 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

W. D. APPEL,
Chairman.

W. H. WHITCOMB,
Secretary.

APPENDIX

RECOMMENDATIONS AFFECTING STANDARDS FOR TEXTILE MATERIALS

In this Appendix are given proposed revisions in certain standards and tentatives covering textile materials, which are referred to earlier in this report. These standards and tentatives appear in their present form in the 1952 Book of ASTM Standards, Part 7, and in the 1953 Supplement to the Book of ASTM Standards, Part 7.

PROPOSED METHOD TO BE PUBLISHED AS INFORMATION

Committee D-13 recommends that the Proposed Method of Test for Predicting Dyeing Behavior of Cotton be published as information only, as appended hereto.[1]

NEW TENTATIVES

The committee recommends the following seven methods for publication as tentative as appended hereto.[2]

Test for Wool Content of Raw Wool—Commercial Scale,
Test for "Fineness" of Cotton Fibers by Resistance to Air Flow (Micronaire Method),
Test for Length of Cotton Fibers by Fibrograph, as a revision of and to replace the test in Sections 11 to 23 of the Tentative General Methods of Testing Cotton Fibers (D 414 – 53 T),
Test for Determination of Build-Up and Spread of Glass Yarn as Wrap (Serving) or Braid Over Electrical Conductors,
Methods of Testing Elastic Fabrics,
Test for Tuft Bind of Pile Floor Coverings,
Test for Yarn Distortion in Woven Fabrics

REVISION OF TENTATIVES

Tentative Methods of Test for Total Wool Fiber Present in Wool in the Grease (D 584 – 53 T):

The committee recommends that these methods be revised as appended hereto.[3]

Tentative Methods of Core Sampling of Wool in Packages for Determination of Percentage of Total Wool Fiber Present (D 1060 – 53 T):

The committee recommends that these methods be revised as appended hereto.[3]

Tentative Methods of Testing and Tolerances for Rayon Tire Cord (D 885 – 53 T):

The committee recommends that this tentative be revised as follows:

Section 25.—Change to read as follows:

25. *Breaking Strength:* (*a*) *Testing Machine.*—A constant-rate-of-load type or a constant-rate-of-traverse type testing machine, together with accessory equipment as specified in Section 19 (*a*), shall be used.

(*b*) *Drying Facilities.*—Adequate drying facilities shall be provided, including the following:

(*1*) *Specimen Holder.*—Either of the following types of holders shall be used for drying the cord:

Spools with tapered cores of corrosion-resistant metal or plastic, and cans made of corrosion-resistant material, large enough to hold the spools. The cans shall have shallow, tight-fitting lids provided with a spindle mounted on the under side, on which the spool can be placed and on which it will rotate freely. The side of the can shall be provided with a narrow slit terminating in a porcelain guide.[4]

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[1] This proposed method appears in the October, 1954, Compilation on Textile Materials.

[2] The new tentatives were accepted by the Society and appear in the 1954 Supplement to Book of ASTM Standards, Part 7.

[3] The revised tentative was accepted by the Society and appears in the 1954 Supplement to Book of ASTM Standards, Part 7.

[4] A suitable guide, designated as No. 990 Worsted, is available from Page-Madden Co., Inc., 79-96 Second St., Mineola, Long Island, N. Y.

Or, racks or specimen-holding boards of suitable design to prevent any change of twist in handling and drying.

(*2*) *Oven*, for drying cords on spools or racks. The oven, large enough to handle the required number of spools or racks, shall be maintained between 105 and 110 C, with a current of air passing through the oven. This air may be predried or preheated if desired. The specimen shall be dried for sufficient time until the loss in weight on heating for an additional 15-min period is less than 0.1 per cent of the original weight of the specimen.

(*c*) *Procedure*.—All rayon tire cord, both woven and on cones, shall be tested after drying in a relaxed condition. Either of the following methods may be used to meet this requirement.

(*1*) *Tapered Spools*.—A piece of paper shall be placed around the core of the special tapered spools in such a manner that the larger half of the spool core is covered. The necessary length of cord shall be wound on the paper. The paper and cord shall be moved to the small end of the spool, taking care to preserve the cord structure as wound, and to avoid tuck-unders. The spool and cord shall then be placed on the lid of the can (with the small end of the core adjacent to the lid) and the assembly heated in an oven as described in Paragraph (*b*), Item (*2*). The oven-dry specimen on the spool on the lid shall be covered with the inverted can, allowing the free end of the cord to protrude through the special guide in the side of the can. The can shall be closed as quickly as possible in order to minimize absorption of moisture, and the unopened can shall be mounted in a convenient position on the side of the testing machine. Approximately 2 yd of the specimen shall be pulled from the can and discarded. The next portion of the specimen shall be placed in the clamps of the tester following the directions given in Section 19 (*b*), and broken immediately. If, for any reason, more than 25 sec are required to place a particular test specimen in the apparatus and break it, the results from that specimen shall be discarded. After breaking a specimen, the cord between the clamps and the can shall be discarded, and a fresh length withdrawn from the can for the next test. The breaking load of the individual specimen shall be obtained from the chart, and the average of all tests shall be reported as the breaking strength of the oven-dry cord.

(*2*) *Racks*.—A series of short lengths of cords shall be secured from cones or woven fabrics, and shall be placed without tension on racks or specimen-holding boards of suitable design to prevent any change of twist in handling. Sufficient slackness shall be allowed to prevent any build-up of tension because of heat-shrinkage during drying. The holder and cord shall then be heated in an oven as described in Paragraph (*b*), Item (*2*). In the event that the specimen holder is not equipped with a cover, the dried cords may be removed from the holder in the oven and placed in a heated specimen holder located conveniently to the testing machine. If the specimen holder is equipped with a properly insulated cover, then the holder containing the dried specimens may be removed from the oven and placed conveniently to the testing machine (Note 1). One cord at a time shall be removed from the sample holder and tested as described in Item (*1*) (Note 2).

NOTE 1.—In this procedure it is intended that the cord shall be tested hot. This condition is fulfilled if the cord temperature at the time of removal from the holder is not less than 150 F.

NOTE 2.—If it is desired to determine the strength and elongation under oven-dry conditions on short lengths of cord by the procedure described in Paragraph (*c*), Item (*1*), a series of specimens (long enough to permit clamping in both clamps) may be tied together and the resulting strand treated as a single cord. If the specimens are less than 1 m. in length, they should be spaced by other lengths of cord which can be discarded. All knots shall be tied in such a way as to prevent any change in twist, and shall be small enough to pass through the porcelain guide in the side of the drying can.

Appendix.—Withdraw the appendix, which deals with a method for twisting rayon tire cords.

Tentative Methods of Testing and Tolerances for Cotton Yarns (D 180 – 52 T):

The committee recommends that this tentative be revised as follows:

Section 2(b).—Change to read as follows:

(*b*) *Moisture Equilibrium*.—It shall be considered that moisture equilibrium is reached when, after free exposure to air in motion, two successive weighings not less than 15 min apart do not interfere by more than 0.1 per cent of the total weight. Moisture equilibrium shall be approached from the dry side. Where samples require drying before conditioning, no heat shall be applied in excess of 125 F.

Section 14(c).—Change to read as follows:

(*c*) When the arithmetic average of the tests on a lot of yarn falls within the tolerances specified, it shall be considered that the lot of yarn conforms to the specified requirements for the particular characteristics tested. When the arithmetic average does not fall within the tolerances, a second set of samples shall be drawn from the original lot or shipment, and the average of the first and second set of tests shall be used.

Tentative Recommended Practice for Interlaboratory Testing of Textile Materials (D 990-52 T):

Section 13(a).—Reverse the order of Items (*1*) and (*2*) as follows and retain Item (*3*) without change.

(*1*) The significance of the results,
(*2*) The conclusions reached, and

Section 13(c).—In the second line of Item (*1*) change the word "as" to read "and." In the second line of Item (*2*), change the word "because" to read "and." In the fourth line of Item (*3*), replace the words "as high as" with the word "of."

Section 6.—Eliminate the definitions of N_L, N_M, N_T, and N_S, replacing them with the definitions of N_M, N_L, N_O, N_S, and N_T shown under Table VI.

Table VI.—Delete the above definitions, but retain the definition for sigma prime squared.

Section 8(b).—In the formula for $\bar{R}_T$ change the denominator to read "$\ldots N_L N_O N_S$."

Section 9(b).—In the formula for $\bar{R}_S$ change the denominator to read "$\ldots N_L N_O$."

Tentative Method of Test for Snag Resistance of Hosiery (D 1115 - 50 T):

The committee recommends that this method be revised as appended hereto.[3]

TENTATIVE REVISIONS OF STANDARD

The committee recommends the following new and revised definitions of terms for publication as tentative, as part of the Standard Definitions of Terms Relating to Textile Materials (ASTM Designation: **D 123 - 53**).

Bright, adj.: 1. *General*.—Characterized by a high degree of luster; brilliant; opposite of dull or dark.

2. *Man-Made Fibers*.—Lustrous, that is, having a high capacity to concentrate reflected light in a specific direction, as compared with the amount reflected in other directions; opposite of dull or matte.

Conformance, n.: Test Methods.—Agreement of the properties of a sample, or lot, with specification requirements.

Course, n.: Knitted Fabrics.—The series of successive loops lying crosswise of a knitted fabric, that is, lying at right angles to a line passing through the open throat to the closed end of the loops.

Dull, adj.: Man-Made Fibers.—Low in luster, that is, showing relatively little tendency to concentrate reflected light in specific directions, and relatively great tendency to scatter light in all directions; having a tendency to produce a diffuse reflection; matte; opposite of bright.

Filler, n.—Nonfibrous material, such as insoluble clays or gypsum, together with starches, gums, etc., added to a fabric to increase its weight or to modify the appearance or handle of the fabric; also referred to as back-sizing.

Filling, n.—Change the note after *Filling, 2*, to read:

NOTE.—In the United Kingdom, filling yarn is designated as weft or woof, and the word filling is used as a collective term for nonfibrous material commonly designated as fillers in the U. S.

Lea Skein, n.—A skein, of length and circumference specified for the specific yarn numbering system involved, commonly used to determine the linear density and the strength of yarns. (See also Skein, Numbering.)

Luster, n.—The property of showing differences in the amount of light reflected in different directions either from local but individually recognizable portions, or from the general surface.

Modulus, Secant, n.—The ratio of change in stress to change in strain between two points on a stress-strain diagram, particularly the points of zero stress and breaking stress.

Pressley Index, n.—A measure of the strength of fiber bundles, determined under prescribed conditions, and expressed in an arbitrary unit, pounds per milligram.

NOTE.—The Pressley Index is the breaking load per unit weight at essentially zero gage length for a bundle of fibers cut to a length of 0.465 in.

Sizing, n.—After the definition given in Standard D 123 add the reference, "See also filler."

Smash.—Delete the definition given in Standard D 123 and retain only the reference, "In Appendix II, See Defect No. 21."

Spinning, n. and *adj.*—The process or processes used in the production of single yarns.

NOTE 1.—*Yarn from Staple Fiber:* The formation of a yarn by a combination of drawing or drafting and twisting prepared strands of fibers such as rovings.

NOTE 2.—*Filament Yarns:* In the spinning of man-made filaments, fiber-forming substances in the plastic or molten state, or in solution, are forced through the holes of a spinneret or die at a controlled rate (extrusion). There are three general methods of spinning man-made filaments: (*1*) *Melt Spinning* is the term applied to the process in which the fiber-forming substance is melted and extruded into air or other gas, or into a suitable liquid, where it is cooled and solidified, as in the manufacture of nylon or glass; (*2*) *Dry Spinning* is the term applied to the process in which a solution of the fiber-forming substance is extruded into a heated chamber to remove the solvent, leaving the solid filament, as in the manufacture of acetate; (*3*) *Wet Spinning* is the term applied to the process in which a solution of the fiber-forming substance is extruded into coagulating media where the polymer is regenerated, as in the manufacture of viscose or cuprammonium rayon.

NOTE 3.—In the manufacture of leaf and bast fiber yarns, the terms "wet spinning" and "dry spinning" refer to the spinning of fibers in the wet state and in the air-dry state, respectively.

NOTE 4.—*Yarn from Filament Tow:* The formation of a yarn from filaments by a combination of cutting or breaking, together with drafting and twisting in a single series of operations.

Strength, Tensile, n.: 2. *Specific.*—The maximum tensile stress expressed in force per unit area of the original specimen. Also termed ultimate tensile strength.

Strength, Tensile, True, n.—The maximum tensile stress expressed in force per unit area of the specimen at the time of rupture.

Strength, Ultimate, Tensile.—See Strength, Tensile.

Tape, n.: 2. *Slide Fasteners.*—A strip of material along one edge of which the bead and scoops are attached, the bead sometimes being integral with the strip.

Toughness, n.—That property of a material by virtue of which it can absorb work.

Toughness, Breaking, n.—The actual work per unit volume (or per unit mass) of material which is required to rupture the material. It is proportional to the area under the load-elongation curve from the origin to the breaking point.

Twist, n.: 3. Calculated from the helix angle between the surface elements of the yarn and the yarn axis, in a structure of known diameter.

Twist, Direction of,[5] *n.*—A yarn has **S** twist if, when held in a vertical position, the spirals around its central axis conform in direction of slope to the central portion of the letter "S," and **Z** twist if the spirals conform in direction of slope with the central portion of the letter "Z."

NOTE.—This definition applies to the twist in single yarns, the ply twist in plied yarns, and the cable or hawser twist in cords.

Wales, n.: 1. *Knitted Fabric.*—A column of loops in successive courses. The column is parallel with the loop axes.

2. *Woven Fabrics.*—One of a series of raised portions or ribs lying warpwise in the fabric.

Warp, Ball, n.—A warp in the form of a twistless rope wound into a ball, cheese, or cake.

Water Resistance (*Fabric*). See ASTM Methods D 583 - 50 T.

Water Repellency (*Textile*). See ASTM Methods D 583 - 50 T.

The committee also recommends that the following definitions now published in the Tentative Definitions of Terms Relating to Textile Materials (ASTM Designation: **D 123 - 53 T**) be continued as tentative without change and published as part of Standard D 123.

1. Bleaching,
2. Compliance: 1. General and 2. Textile,
3. Creep,
4. Creep, Primary,
5. Creep, Secondary,
6. Curve, Load-Deformation,
7. Curve, Stress-Strain,
8. Curve, Tensile Hysteresis,
9. Deformation,
10. Deformation, Delayed; Creep,
11. Deformation, Immediate Elastic,
12. Lea,
13. Lea Skein and Note,
14. Modulus,
15. Modulus, Tangent,

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[5] *Editorial Note:* The current definition of "Twist, Direction of" applies only to single yarns, though this limitation is not stated. The revision proposed is generally applicable as noted.

16. Modulus, Young's,
17. Ribbon, Slit, or Cut,
18. Ribbon, Woven,
19. Strain, Tensile,
20. Strength, Breaking,
21. Strength, Tensile,
22. Strength, Tensile, Ultimate,
23. Stress, General,
24. Stress, Tensile,
25. Tenacity,
26. Tenacity, Breaking.
27. Top 1, Worsted Process,
28. Woolen-Spun and Note,
29. Worsted-Spun and Note, and
30. Yarn Uneveness, all 6 definitions.

Standard Specifications for Woven Asbestos Cloth (D 677 – 50):

The committee recommends the following tentative revision of this standard:

Table I.—Change to read as shown in the accompanying Table I.

TABLE I.—PHYSICAL PROPERTIES AND AVAILABLE GRADES OF REPRESENTATIVE ASBESTOS CLOTHS.

Style Number	Weight, lb per sq yd	Thickness, in.	Construction		Yarn Number		Grades					
			Warp	Filling	Warp	Filling	Commercial	Underwriters	A	AA	AAA	AAAA
17P24[a]	1.05	0.035	16	15	24/2	24/2		X				
20P28[a]	1.25	0.036	27	13	28/2	28/2		X				
22P16[a]	1.40	0.051	18	10	16/2	16/2		X			X	
24P18[a]	1.50	0.050	20	14	18/2	18/2		X				
26P14[a]	1.65	0.053	14	14	14/2	14/2		X		X		
34P10[a]	2.10	0.062	16	9	10/2	10/2	X	X		X		
36P10[a]	2.25	0.070	18	9	10/2	10/2	X	X		X	X	
38P12[a]	2.40	0.065	20	12	12/2	12/2					X	
39P12[a]	2.45	0.075	27	9	12/2	12/2					X	
40P10[a]	2.50	0.075	20	10	10/2	10/2	X	X		X	X	
48P10[a]	3.00	0.080	19	9	10/3	10/2	X	X		X	X	
76P10DC[a, b]	4.75	0.135	37	16	10/2	10/2	X	X				
40H14[c]	2.50	0.070	27	14	14/2	14/2	X	X				
53T12[d]	3.33	0.080	36	12	12/2	12/2					X	X
59T12[d]	3.70	0.080	40	14	12/2	12/2						X

[a] P = plain weave.
[b] DC = double cloth.
[c] H = herringbone weave.
[d] T = twill weave.

Standard Methods of Testing and Tolerances for Certain Wool and Part Wool Fabrics (D 462 – 53):

The committee recommends the following tentative revision of this standard:

Section 9.—Designate the weight test in this section as the Preferred Method, and add the following alternate weight test as a new Section 10, renumbering the subsequent sections accordingly:

10. (*a*) *Weight, Alternate Method.*—A specimen having an area of at least 20 sq in. (or a number of specimens not less than 2 in. square and having a total area of at least 20 sq in.) shall be cut from the fabric. The oven-dry, clean weight shall be determined on this specimen. Unless a specimen the full width of the fabric is used, no specimen shall be taken nearer the selvedge than one tenth the width of the fabric.

NOTE 1.—This method is intended for use when a small sample of fabric is sent to the laboratory for test. The result is considered to be applicable to the sample, but not to the piece or lot of goods from which the sample was taken, unless the number of samples and method of sampling are specified and agreed upon by those concerned.

(*b*) *Reference Weight* (*Including Standard Regain*).—Reference weight of all woven wool fabrics or woven fabrics of blends containing wool shall be the oven-dry, clean weight of the fabric plus its standard regain. For woven fabrics composed of blends containing wool, the standard moisture regain shall be calculated as follows:

$$\text{Standard regain, per cent} = \frac{(W \times 13.6) + (A \times R_a) + (B \times R_b) + \cdots (N \times R_n)}{100}$$

where:

W = percentage wool (clean, dry basis),

$A, B, \ldots N$ = percentage (clean, dry basis) of fibers $a, b, \ldots n$, respectively, and

$R_a, R_b, \ldots R_n$ = percentage of standard regains of fibers $a, b, \ldots n$, respectively.

NOTE 2.—*Standard Regain.*—The standard moisture regain shall be 13.6 per cent for woven fabrics containing all wool. The standard regains of the fibers other than wool shall be as follows:

	Regain, per cent
Bemberg	12.5
Silk	11.0
Viscose	11.0
Vicara	11.0
Cotton	7.0
Acetate	6.5
Nylon	4.5
Orlon	2.0
Dynel	1.0
Acrilan	1.0
Dacron	1.0

In the case of synthetic fibers not listed in the above table, the standard regain value as established by the manufacturer shall apply.

REVISION OF STANDARD AND REVERSION TO TENTATIVE

Method of Test for Maximum Residual Shrinkage of Silk and Rayon, and Acetate Woven Fabrics (D 416 - 39):

The committee recommends that this method be reverted to tentative and revised as appended hereto.[6]

Standard Method of Test for Vegetable Matter in Scoured Wool (D 1113 - 52):

The committee recommends that this method be revised and reverted to tentative as appended hereto.[6]

ADOPTION OF TENTATIVES AS STANDARDS

Tentative Definitions of Terms Relating to Textile Materials (D 123 - 53 T):

On the recommendation of Subcommittee B-2, the committee proposes that the definitions for the following 10 terms now appearing in Tentative D 123 - 53 T be approved for submission to letter ballot of the Society for adoption as standard:

1. Break Factor,
2. Cloth,
3. Fiber,
4. Hank,
5. Misdraw,
6. Shiner,
7. Sticker,
8. Tow,
9. Twist, and
10. Warp.

Tentative Methods of Quantitative Analysis of Textiles (D 629 - 46 T):

The committee recommends that this tentative be approved for reference to letter ballot of the Society for adoption as standard with the following revisions:

New Section.—Insert a new Section 13 and Note 13 as follows, renumbering the subsequent sections and Notes accordingly:

METHOD FOR ANALYZING MIXTURES CONTAINING NYLON 66

13. *Nylon 66.*—(*a*) This procedure is applicable to mixtures of nylon 66 with wool, cotton, viscose, or cuprammonium rayon. It is not suitable for analyzing mixtures of nylon 66 with acetate or cultivated silk.

(*b*) *Test Specimen.*—A specimen of approximately 2 g shall be analyzed. Remove the nonfibrous materials in accordance with the procedure described in Section 5, and determine the oven-dry weight of the clean fiber residue, weight *C*. Before making the analysis, the yarns should be cut into lengths of about 2 to 4 mm to facilitate dissolving.

(*c*) *Apparatus Required:*

(*1*) *Erlenmeyer or Other Suitable Flask, having a capacity of 500 ml, preferably with a ground-glass stopper.*

(*2*) *Fritted Glass Filtering Crucible,* medium porosity.

(*3*) *Suction Flask,* with adapter.

(*4*) *Weighing Bottle,* suitable for containing fritted glass filtering crucible.

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[6] The revised method was accepted by the Society and appears in the 1954 Supplement to Book of ASTM Standards, Part 7.

(*d*) *Reagents:*

(*1*) *Hydrochloric Acid* (*sp gr 1.139*).—Dilute HCl (sp gr 1.19) with distilled water until the specific gravity of the solution is 1.139 at 20 C. A glass hydrometer is convenient for determining the specific gravity of the solution.

Hydrochloric Acid (*2:3*).—Mix 2 volumes of HCl (sp gr 1.19) with 3 volumes of distilled water.

Ammonium Hydroxide (8:92).—Mix 8 volumes of NH_4OH (sp gr 0.90) with 92 volumes of distilled water.

(*e*) *Procedure.*—Immerse the specimen in 200 ml HCl (sp gr 1.139) in a 500-ml stoppered flask, shake vigorously, and let stand for 15 min at a room temperature of 15 to 25 C. Shake again and leave for a further 15 min, shake for a third time, and filter the mixture through a weighed fritted glass crucible. Wash into the crucible any residue left in the flask, using a little more HCl (sp gr 1.139). Apply suction to drain the excess liquor from the fiber residue.

Wash the residue in the crucible with 80 ml of HCl (2:3) and then with distilled water until the filtrate is neutral to litmus. Disconnect the suction, and add to the crucible about 80 ml of NH_4OH (8:92), allowing the fiber residue to soak for 10 min before applying suction to drain it. Wash the residue with about 250 ml of distilled water, allowing it to soak in the water for about 15 min. After the final washing, suck the fiber residue reasonably free from the rinse water and dry in an oven at 105 to 110 C to constant weight, weight H (Note 12).

(*f*) *Calculation.*—Calculate the nylon content from Eq 20, Section 14 (Note 13).

NOTE 13.—Cotton and viscose rayon are slightly soluble in HCl (sp gr 1.139). In analyzing blends containing these fibers, the following corrections should be applied:

Cotton: Increase weight of cotton residue by 1.0 per cent.

Viscose Rayon: Increase weight of viscose residue by 1.2 per cent.

Section 13.—Renumber as Section 14 and add the following Eq 20:

$$\text{Nylon, per cent} = \frac{C - H}{C} \times 100 \quad \text{..(20)}$$

Section 14.—Renumber as Section 15, and renumber Eqs 20, 21, and 22 as 21, 22, and 23.

The committee recommends that the following 14 tentatives be approved for reference to letter ballot of the Society for adoption as standard without revision:

Tentative Methods of Test for:

Small Amounts of Copper and Manganese in Textiles (D 377 - 52 T),
Colorfastness to Light of Textiles (D 506 - 52 T),
Resistance of Textile Fabrics and Yarns to Insect Pests (D 582 - 49 T),
Water Resistance of Textile Fabrics (D 583 - 52 T),
Evaluating Compounds Designed to Increase Resistance of Fabrics and Yarns to Insect Pests (D 627 - 49 T),
Resistance of Textile Materials to Microorganisms (D 684 - 53 T),
Evaluating Treated Textiles for Permanence of Resistance to Microorganisms (D 862 - 45 T),
Shrinkage in Laundering of Knit Cotton Fabrics (D 1231 - 52 T),
Shrinkage in Laundering of Knit Rayon Fabrics (D 1232 - 52 T),
Sampling Cotton Fibers for Testing (D 1441 - 52 T),
Fiber Weight per Unit Length and Maturity of Cotton Fibers (Array Method) (D 1442 - 52 T), and
Sampling and Testing Staple Length of Wool in the Grease (D 1234 - 52 T).

Tentative Specifications and Methods of Test for:

Asbestos Yarns (D 299 - 52 T), and
Asbestos Lap (D 1061 - 52 T).

REPORT OF COMMITTEE D-14
ON
ADHESIVES*

Committee D-14 on Adhesives held two meetings during the year: one at the Research Center of Wyandotte Chemicals Corp., Wyandotte, Mich., on October 14 and 15, 1953, and one at Mellon Institute, Pittsburgh, Pa., on April 7 and 8, 1954.

At the present time Committee D-14 consists of 103 members, of whom 37 are classified as producers, 42 as consumers, and 24 as general interest members.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, R. F. Blomquist.
Vice-Chairman, G. F. Lipsey.
Secretary, C. K. M. Winne.
Membership Secretary, Alan Marra.

Recommendations Accepted by the Administrative Committee on Standards

Subsequent to the 1953 Annual Meeting, Committee D-14 presented to the Society through the Administrative Committee on Standards the following recommendations:

Tentative Revision of:

Standard Definitions of Terms Relating to Adhesives (D 907 – 52), consisting of the addition of definitions for Diluent, Plywood, Glued Laminated Wood, and Built-Up Laminated Wood.

Tentative Methods of:

Test for Adhesives Relative to their Uses as Electrical Insulation (D 1304 – 54 T).

These recommendations were accepted by the Standards Committee on March 3, 1954, and March 17, 1954, respectively. The new tentative methods are appended hereto.[1]

Proposed Methods to be Published as Information

Committee D-14 recommends that the following three proposed methods be published as information only, as appended to this report:[2]

Proposed Method for Testing Bonded Specimens as Cantilever Beams under Repeated Constant Deflection,

Proposed Method of Test for Susceptibility of Dry Adhesive Films to Attack by Roaches, and

Proposed Method of Test for Susceptibility of Dry Adhesive Films to Attack by Laboratory Rats.

New Tentatives

The committee recommends that the following methods be accepted for publication as tentative as appended hereto:[1]

Method of Test for Storage Life of Adhesives by Consistency and Bond Strength.

Method of Test for Working Life of Liquid or Paste Adhesives by Consistency and Bond Strength.

Adoption of Tentative as Standard

The committee recommends that the Tentative Specifications for Impact Strength of Adhesives (**D 950 – 52 T**)[3] be approved for reference to the letter ballot of the Society for adoption as standard without revision.

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13–18, 1954.

[1] The new methods appear in the 1954 Supplement to Book of ASTM Standards, Part 7.

[2] The proposed methods appear in the September, 1954, Compilation on Adhesives.

[3] 1952 Book of ASTM Standards, Part 7.

TENTATIVES CONTINUED WITHOUT REVISION

The committee recommends that the following tentatives be continued in their present status without revision, pending further evaluation work and study:

Recommended Practice for:

Determining the Effect of Artificial (Carbon Arc Type) and Natural Light on the Permanence of Adhesives (D 904 – 46 T),

Determining Strength Development of Adhesive Bonds (D 1144 – 51 T), and

Determining the Effect of Moisture and Temperature on Adhesive Bonds (D 1151 – 51 T).

Method of Test for:

Consistency of Adhesives (D 1084 – 50 T),

Resistance of Adhesives for Wood to Cyclic Accelerated Service Conditions (D 1183 – 51 T),

Strength of Adhesives on Flexural Loading (D 1184 – 51 T), and

Effect of Bacterial Contamination on Permanence of Adhesive Preparation and Adhesive Bonds (D 1174 – 51 T).

The recommendations appearing in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[4]

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Strength Properties (C. B. Heming, chairman) has prepared a tensile (cross-lap) method of test which the committee is recommending for publication as tentative.[5] The method of butt-joint testing has developed lively interest, and preliminary drafts of tensile, cleavage, and impact methods of test are under way. Revision of Methods D 1184 – 51 T on Flexural Strength is under consideration.

Subcommittee III on Permanence (R. F. Blomquist, chairman) has prepared the two methods on the susceptibility of adhesives to attack by cockroaches, and to attack by vermin, which are being recommended for publication as information. Work is continuing on the revision of Method D 1183 – 51 T.

Subcommittee IV on Working Qualities (M. Petronio, chairman) has prepared the new methods on adhesive storage life, and adhesive working life, which are recommended for publication as tentative. Two methods of test for consistency of adhesives are under study. A method of test on the gap filling qualities of adhesives for wood is now under consideration.

Subcommittee V on Specifications (F. H. Bair, chairman).—Work on a specification for adhesives for acoustical tile is progressing through a joint task group of Committee C-20 on Acoustical Materials, and Committee D-14. Work has been started on a specification for adhesives for fiber-board boxes.

Subcommittee VI on Nomenclature (F. W. Reinhart, chairman).—Definitions of the terms "diluent," "plywood," "glued laminated wood," "built-up laminated wood" have been accepted by the Administrative Committee on Standards. New definitions and revisions of certain terms are under consideration by the subcommittee.

Subcommittee VII on Research (G. W. Koehn, succeeding R. C. Platow as chairman) had a discussion meeting at the 1953 Fall meeting on various aspects of adhesion. At the Spring Meeting Mr. Gruse of Mellon Institute gave a comprehensive talk on the various aspects of lubrication and the attendant problems of adhesion.

Subcommittee VIII on Electrical Properties (H. A. Perry, chairman) prepared the Methods of Test for Adhesives Relative to Use as Electrical Insulation

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[4] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

[5] See Editorial Note, p. 505.

(D 1304 - 54 T) referred to earlier in this report as accepted by the Administrative Committee on Standards. The methods are appended hereto.[1]

This report has been submitted to letter ballot of the committee, which consists of 103 voting members; 84 members have returned their ballots, of whom 79 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

GERALD REINSMITH,
Chairman.

L. M. PERRY,
Secretary.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee D-14 presented to the Society through the Administrative Committee on Standards the Tentative Method of Testing Cross-Lap Specimens for Tensile Properties of Adhesives. The method was accepted by the Standards Committee on September 1, 1954, and it appears in the 1954 Supplement to Book of ASTM Standards, Part 7, bearing the designation D 1344 - 54 T.

REPORT OF COMMITTEE D-15

ON

ENGINE ANTIFREEZES*

Committee D-15 on Engine Antifreezes held two meetings during the year: the first in Cincinnati, Ohio, on October 9, 1953, and the second in Washington, D. C., on March 19, 1954. The Advisory Committee and subcommittees held meetings concurrently.

There have been five resignations and four additions to the list of committee members during the year. At present the committee is composed of 40 active members, of whom 20 are classified as producers, 9 as consumers, and 11 as general interest members.

The one change in subcommittee chairmanship occurring during the year was the appointment of C. H. Sweatt to succeed E. F. Harford as chairman of Subcommittee VI on Simulated and Actual Service Testing.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, H. R. Wolf.

Vice-Chairman, R. E. Mallonee.

Secretary, C. F. Graham.

Advisory Committee, J. M. Clark, V. O. Hatch, J. D. Klinger, J. B. Stobbart, and R. E. Vogel.

ADOPTION OF TENTATIVES AS STANDARD

Committee D-15 recommends that the following tentative methods be approved for reference to letter ballot of the Society for adoption as standard without change:

Tentative Method of Test for:

Reserve Alkalinity of Concentrated Engine Antifreezes (**D 1121 – 50 T**),[1]

Water in Concentrated Engine Antifreezes by the Iodine Reagent Method (**D 1123 – 50 T**),[1]

Sampling and Preparation of Aqueous Solutions of Engine Antifreezes for Testing Purposes (**D 1176 – 52 T**),[1] and

Freezing Point of Aqueous Engine Antifreeze Solution (**D 1177 – 52 T**).[1]

APPROVAL AS AMERICAN STANDARDS

The committee recommends that upon adoption as standard of the above four methods, they be submitted to the American Standards Assn. for approval as American Standard together with the following two methods:

Method of Test for:

Boiling Point of Engine Antifreezes (D 1120 – 53), and

Specific Gravity of Concentrated Engine Antifreezes by the Hydrometer (D 1122 – 53).

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[2]

ACTIVITIES OF SUBCOMMITTEES

Subcommittee III on Physical Properties (R. E. Vogel, chairman) reviewed the acceptibility and general applicability of Method D 1120 – 53 for Boiling Point of Engine Antifreezes and Method D 1122 – 53 for Specific Gravity of Concentrated Engine Antifreezes by the Hydrometer and recommended their approval as American Standard.

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13–18, 1954.

[1] 1952 Book of ASTM Standards, Part 5.

[2] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

Subcommittee IV on Chemical Properties (E. G. Travis, chairman).—As a result of cooperative test work carried out, a precision section was recommended for inclusion in the Method for pH of Concentrated Engine Antifreezes (D 1287 – 53 T). The Tentative Method of Test for Reserve Alkalinity of Concentrated Antifreezes (D 1121 – 50 T), and Method of Test for Water in Concentrated Engine Antifreezes by the Iodine Reagent Method (D 1123 – 50 T) were reviewed and found satisfactory for adoption as standard.

Study Group on Detection of Antifreezes in Crankcase Oil (A. G. Barber, chairman).—At the most recent meeting of Committee D-15, it was the consensus that the problem of coolant leakage into the crankcase has been greatly alleviated in the field. For this reason, it was felt that further investigations by Committee D-15 of antifreeze detection methods in used oil is no longer warranted. Accordingly, this study group has been discharged.

Subcommittee V on Effects of Antifreeze on Rubber Hose (O. W. Chandler, chairman).—Further work by the subcommittee in attempting to develop a simple laboratory rubber immersion test for the evaluation of the effects of antifreeze on rubber hose has resulted in considerable progress. A third series of tests was completed and resulted in a tentative procedure which appears to be capable of differentiating between antifreezes having materials deleterious to rubber hose and those which have little or no effect on rubber hose. A fourth series of cooperative tests on this method is now being undertaken in order to evaluate further its limitations with a greater number of antifreezes tested by a larger number of laboratories.

Subcommittee VI on Simulated and Actual Service Testing (C. H. Sweatt, chairman).—A 336-hr beaker type corrosion test procedure has been evaluated by twelve laboratories, using four different antifreezes and tap water as a control. The procedure was found to be generally satisfactory, and the metal specimen weight loss data indicated that uninhibited or poorly inhibited solutions could be differentiated from materials that are suitable for further testing. Some revisions are required in the procedure and general agreement has been reached on the scope for this beaker test.

The Study Group on Test Methods (C. H. Sweatt, chairman) has served as an analysis panel for the cooperative corrosion test program being conducted by Subcommittee VI. A comprehensive summary of collaborative test results was submitted, certain modifications in the test procedure were recommended, and a tentative scope was prepared for the subcommittee. A revised corrosion test procedure will be prepared for approval by the subcommittee.

This report has been submitted to letter ballot to the committee, which consists of 40 voting members; 33 members have returned their ballots, of whom 32 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

H. R. WOLF,
Chairman.

C. F. GRAHAM,
Secretary.

REPORT OF COMMITTEE D-16

ON

INDUSTRIAL AROMATIC HYDROCARBONS AND RELATED MATERIALS*

Committee D-16 on Industrial Aromatic Hydrocarbons and Related Materials and its subcommittees held meetings in Washington, D. C., on February 1 and 2, 1954, during Committee Week. Additional meetings of both the committee and its subcommittees are scheduled during the 1954 Annual Meeting.

The committee is working with Subcommittee 17 on Thermometers, of Committee E-1 on Methods of Testing, regarding revision of specifications for the 70 to 120 C and 100 to 160 C distillation thermometers specified as alternates in the Standard Method of Test for Distillation of Industrial Aromatic Hydrocarbons (D 850 - 50), and also on a series of thermometers designed for solidification point testing according to a procedure now under consideration.

A membership subcommittee has been appointed, with K. H. Ferber as chairman, to whom suggestions as to companies who are interested in topics within the scope of this committee should be addressed.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, D. F. Gould.
Vice-Chairman, W. E. Sisco.
Secretary, F. J. Powell.

EDITORIAL CHANGE

The committee recommends the following editorial change in the Standard Method of Test for Acid Wash Color of Benzene, Toluene, Xylenes, Refined Solvent Naphthas and Similar Industrial Aromatic Hydrocarbons (**D 848 - 47**)[1]:

Scope.—Add the following note:

NOTE.—The acid wash test should not be applied to saturated hydrocarbons, petroleum naphthas, or to non-hydrocarbon solvents.

ACTIVITIES OF SUBCOMMITTEES

Subcommittee A on Monocyclic Aromatics (S. S. Kurtz, Jr., chairman).—The following items are being actively studied through cooperative tests:

(1) Bromine Index Determination by Potentiometric Titration. The method appended to this report[2] has been circulated to the committee as information.

(2) Determination of Thiophene.

(3) Correlation of Distillation Methods. These studies are being carried out in connection with ASTM Method of Test for Distillation of Industrial Aromatic Hydrocarbons (D 850), and ASTM Method of Test for Distillation Range of Lacquer Solvents and Diluents (D 1078).

The subcommittee has also set up task groups to consider spectrographic methods, and to formulate specific gravity conversion tables for benzene, toluene, and xylenes.

Proposals for specifications for benzene, toluene, and xylenes to be under the joint jurisdiction of Committee D-1 on Paint, Varnish, Lacquer, and Related

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13-18, 1954.

[1] 1952 Book of ASTM Standards, Part 5.

[2] See p. 510.

Products and Committee D-16 will be considered at the June meeting.

Subcommittee B on Polycyclic Aromatics (M. Mitchell, chairman) has under consideration tests applicable to refined naphthalene for determination of solidification point, color, and moisture. Methods for wash test, ash, and nonvolatile matter and benzene insoluble matter have been agreed upon. As soon as agreement is reached on the first series, cooperative tests will be started.

Subcommittee C on Phenolic Compounds (V. S. Morello, chairman) is working on methods for determination of solidification point, water content, water solubility, and oil and naphthalene. In several cases methods currently available are not considered to be satisfactory and attempts are being made to effect improvement.

Subcommittee D on Nitrogen Heterocyclics (W. E. Sisco, chairman) is developing methods for refined pyridine covering the determination of distillation range, water content, and color. Tests for oil content and permanganate reactions are being considered. Similar methods plus a solidification point test are also being developed for refined quinoline.

This report has been submitted to letter ballot of the committee, which consists of 44 members; 35 returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

D. F. GOULD,
Chairman.

F. J. POWELL,
Secretary.

APPENDIX

PROPOSED METHOD OF TEST FOR BROMINE INDEX OF AROMATIC HYDROCARBONS BY POTENTIOMETRIC TITRATION[1,2]

This is a proposed method and is published as information only. Comments are solicited and should be addressed to the American Society for Testing Materials, 1916 Race St., Philadelphia 3, Pa.

Scope

1. This method covers a procedure for determination of the bromine index of aromatic hydrocarbons by potentiometric titration.

Outline of Method

2. The sample is dissolved in a special solvent and titrated with 0.02 *N* bromide - bromate solution at room temperature. Shielding from light is not necessary. End point detection is by a potentiometric method using the combination of glass *versus* platinum electrodes.

Apparatus

3. (*a*) *Titrimeter or pH Meter* equipped with glass and platinum electrodes. The pair of electrodes shall be mounted to extend well below the liquid level.

(*b*) *Buret*, 25 ml.

(*c*) *Mechanical Stirrer* that will furnish a rapid stirring action, but not such vigorous stirring that air bubbles will be drawn down to the electrodes of the titrimeter or pH meter.

(*d*) *Beaker.*

Reagents

4. (*a*) *Titration Solvent* conforming to Section 5 (*a*) of the Tentative Method of Test for Bromine Number of Petroleum Distillates (Electrometric Method) (ASTM Designation: D 1159).[3]

(*b*) *Standard Potassium Bromide - Bromate Solution* (*0.02 N*).—Prepare and standardize as directed in Section 5 (*b*) of Method D 1159, except to make suitable adjustments for a 0.02 *N* solution instead of 0.5 *N*.

Procedure

5. (*a*) Place 100 ml of titration solvent in the titration beaker and either weigh or pipet the appropriate size sample into the solvent. Use the following table as a guide in choice of sample size:

Bromine Index	Grams of Sample
0 to 10	25 to 30
10 to 50	15 to 25
50 to 100	10 to 15
100	10

NOTE.—The size of sample is limited by the tolerance of the solvent - hydrocarbon sample mixture for water. If there is too much hydrocarbon or too large a titration with aqueous bromide - bromate solution, the titration mixture may eventually separate into two phases. If the mixture becomes cloudy or separates into two phases, discard the analysis and repeat with a smaller sample.

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[1] This proposed method is under the jurisdiction of the ASTM Committee D-16 on Industrial Aromatic Hydrocarbons and Related Materials.

[2] Published as information, June, 1954.

[3] 1952 Book of ASTM Standards, Part 7.

TABLE I.—SUMMARY OF COOPERATIVE BROMINE INDEX DATA FOR BENZENE BLENDS.

Sample Number	1		2		3		4		5		6		7		8	
Cyclohexene added, ppm	none		89.1		213		470		none		93.5		213		451	
Thiophene added, ppm	none		none		none		none		801		806		815		788	
Expected bromine index	4.1		21.5		45.7		95.6		4.1		22.3		45.6		92.0	
	Avg	Δ from Avg	Avg	Δ from Avg	Avg	Δ from Avg	Avg	Δ from Avg	Avg	Δ from Avg	Avg	Δ from Avg	Avg	Δ from Avg	Avg	Δ from Avg
Laboratory Designation																
1	5.4	+1.1	25.7	−0.3	55.3	+2.8	115.6	+7.4	3.3	−2.6	34.7	+7.2	52.6	−0.6	106.9	+0.1
2	4.3	0	27.3	+1.3	54.3	+1.8	115.7	+7.5	5.3	−0.6	30.5	+3.0	55.4	+2.2	107.0	+0.2
3	3.8	−0.5	23.9	−2.1	51.6	−0.9	105	−3.2	3.3	−2.6	28.0	+0.5	52.4	−0.8	111	+4.2
4	4.2	−0.1	25.0	−1.0	51.6	−0.9	105.7	−2.5	6.2	+0.3	27.4	−0.1	53.4	+0.2	105.0	−1.8
5	1.7	−2.6	24.5	−1.5	44.5	−8.0	110	+1.8	10.5	+4.6	24.5	−3.0	46	−7.2	98	−8.8
6	4.4	+0.1	27.7	+1.7	58.6	+6.1	113.2	+5.0	5.3	−0.6	29.9	+2.4	58.5	−5.3	121.2	+14.4
7	5.5	+1.2	34.5	+8.5	57.2	+4.7	116.8	+8.6	10.2	+4.3	32.8	+5.3	63.4	+10.2	116.4	+9.6
8	3.3	+1.0	22.5	−3.5	45.0	−7.5	97.0	−11.2	8.0	+2.1	20.0	−7.5	46.0	−7.2	102.5	−4.3
9	2.7	−1.6	21.4	−4.6	46.5	−6.0	97.9	−10.3	2.2	−3.7	22.1	−5.4	44.4	−8.8	95.0	−11.8
10	8.8	+4.5	35.5	+9.5	65.2	+12.7	151.3[a]	+43.2[a]	10.2	+4.3	32.2	+4.7	61.2	+8.0	118.5	+11.7
11	5.0	+0.7	27.0	+1.0	55.5	+3.0	111.9	+3.7	5.3	−0.6	26.0	−1.5	56.2	+3.0	117.2	+4.4
12	4.1	−0.2	24.3	−1.7	52.3	−0.2	114.7	+6.5	6.8	+0.9	28.7	+1.2	59.0	+5.8	112.0	+5.2
13	4.1	−0.2	24.0	−2.0	49.5	−3.0	101.5	−6.7	4.4	−1.5	26.7	−0.8	50.3	−2.9	97.0	−9.8
14	3.1	−1.2	21.3	−4.7	47.8	−4.7	102.0	−6.0	1.0	−4.9	21.6	−5.9	46.4	−6.8	93.1	−13.7
Average, all laboratories	4.3	1.1	26.0	3.1	52.5	4.5	108.2	6.2	5.9	2.4	27.5	3.5	53.2	4.9	106.8	7.1
Maximum deviations	...	+4.5	...	+9.5	...	+12.7	...	+7.5	...	+4.6	...	+7.2	...	+10.2	...	+14.4
	...	−2.6	...	−4.7	...	−7.5	...	−11.2	...	−4.9	...	−7.5	...	−8.8	...	−13.7
Deviation of average from expected	+0.2		+4.5		+6.8		+12.6		+1.8		+5.2		+7.6		+14.8	

[a] This figure was excluded from the average.

(*b*) Set the beaker in place on the titration stand, insert the glass and platinum electrodes, start the stirrer, and commence the titration with 0.02 *N* bromide - bromate solution. Conduct the titration in a manner similar to the usual potentiometric titrations, taking readings of emf *versus* milliliters of titrant. Take care that the rate of addition of bromide - bromate solution does not exceed 0.5 ml per min. As the end point is approached, add the reagent in 0.2 ± 0.05-ml increments and take the corresponding emf reading. Consider the end point to be reached when a 0.2-ml increment of reagent causes a deflection of at least 0.075, based on the maximum deflection after the addition of the reagent.

(*c*) Run a titration blank on the solvent, following the same procedure but omitting the sample.

Calculation

6. The bromine index shall be calculated as follows:

$$\text{Bromine index} = \frac{(A - B) \times N \times 7990}{W}$$

where:

A = milliliters of bromide - bromate solution used for titration of the sample,

B = milliliters of bromide - bromate solution used for titration of the blank,

N = normality of the bromide - bromate solution, and

W = grams of sample used.

SUPPORTING DATA

Supporting data, obtained in cooperative tests on this proposed method of test for bromine index, are given in Tables I and II.

TABLE II.—COMPARISON OF DIFFERENCES ON SAMPLES WITH AND WITHOUT THIOPHENE.

Sample pair	5 and 1	6 and 2	7 and 3	8 and 4
Thiophene difference, ppm	801	806	815	788
Expected bromine index difference	0	0.8	—0.1	—3.6
Laboratory Designation				
1	−2.1	+9.0	−2.7	−8.7
2	+1.0	+3.2	+1.1	−8.7
3	−0.5	+4.1	+0.8	+6.0
4	+2.0	+2.4	+1.8	−0.7
5	+8.8	0	+1.5	−12.0
6	+0.9	+2.2	−0.1	+7.0
7	+4.7	−1.7	+6.2	−0.4
8	+4.7	−2.5	+1.0	−5.5
9	−0.5	+0.7	−2.1	−2.9
10	+1.4	−3.3	−4.0	−32.1[a]
11	+0.3	−1.0	+0.7	−0.7
12	+2.7	+4.4	+6.7	−2.7
13	+0.3	+2.7	+0.8	−4.5
14	−2.1	+0.3	−1.4	−8.9
Average difference between pairs, all laboratories	+1.6	+1.5	+0.7	−3.3
Deviation of average difference from expected difference	+1.6	+0.7	+0.8	+0.3

[a] This figure was excluded from the average.

REPORT OF COMMITTEE D-17
ON
NAVAL STORES*

Committee D-17 on Naval Stores held one meeting during the past year: on July 2, 1953, in Atlantic City, N. J., during the Annual Meeting of the Society. An informal joint meeting of all subcommittees was held the previous day.

The committee lost one member by resignation, Mr. E. E. McSweeney, who represented Battelle Memorial Inst. A successor has not yet been named.

The importance of crystallization in certain industrial uses of rosin and the inclusion of various test methods and requirements on this undesirable property in some consumer specifications for rosin resulted in reactivating Subcommittee II on Crystallization of Rosin. Further reference to this work is made under subcommittee activities.

A trial set of glass standards or "types" for rosin, made from Lovibond (British) glass by the firm of Tintometer, Ltd., of Salisbury, England, has been received direct from the manufacturers for colorimetric examination and comparison with the U. S. Official Standards for rosin, made of glass by the U. S. Department of Agriculture. The new Lovibond rosin types are assembled in a manner similar to the U. S. Standards by mounting the cemented combinations of the Lovibond glasses in a ⅞-in. square metal sleeve. The agreement of the new types with the U. S. Standards, both as to color and appearance, was found to be very good for most of the grades. Recommendations regarding indicated minor color changes to bring the remaining grades into better agreement have been made. It is understood that the new Lovibond glass types or standards for rosin will be offered for sale in the near future through the New York agents of the manufacturer. Additional information on this subject can be obtained from the chairman of the committee, Mr. V. E. Grotlisch, Naval Stores Branch, Tobacco Division, AMS, U. S. Dept. of Agriculture, Washington, D. C.

The ASTM Standard Specifications for Spirits of Turpentine (D 13 - 51), now recognized by the Federal government and approved as American Standard by the American Standards Assn, are being considered for adoption by the International Organization for Standardization (ISO) Committee on Paints, Varnishes and Similar Products. The ASTM is participating in the work of this ISO committee through the ASA. Due to the fact that the United States is the principal producing and using country for the several kinds of wood turpentine, with no foreign production of steam distilled wood turpentine, certain interests abroad proposed that the term "spirits of turpentine" be limited for use to gum spirits of turpentine. This, of course, would be in conflict with the provisions of the Federal Naval Stores Act. For the purpose of providing international standard specifications for turpentine, suggestion was made at a meeting at The Hague, Holland, some months ago that a distinct and separate specification be provided for gum spirits of turpentine, on the one hand, and that the several kinds of wood turpentine, on the other hand, be covered by a different set of specification requirements. No action has been taken on this proposal.

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13-18, 1954.

The Standard Method of Test for Toluene Insoluble Matter in Rosin, (D 269 – 52), by which contamination with foreign matter such as sand, dirt, wood chips or bark is determined, has been approved as American Standard by the ASA.

The chairman of the committee, serving as its representative on Subcommittee 18 on Hydrometers of Committee E-1 on Methods of Testing, reports that specifications for ASTM specific gravity hydrometers have been developed for both light and heavy liquids over the entire range from 0.645 to 1.505. The individual hydrometers will have slightly overlapping ranges of about 0.050. A special alcohol hydrometer having a range of 0.945 to 1.005 is included. Most of the terpene oils can be tested with such hydrometers.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, V. E. Grotlisch.
Vice-Chairman, J. L. Boyer.
Secretary, W. A. Kirklin.

ADOPTION OF TENTATIVE AS STANDARD

The committee, after further consideration and on the recommendation of its Subcommittees IV on Chemical Analysis of Rosin and V on Tall Oil, recommends that the Tentative Method of Test for Rosin Acids in Fatty Acids (**D 1240 – 52 T**),[1] be approved for reference to letter ballot of the Society for adoption as standard without revision.

TENTATIVE CONTINUED WITHOUT REVISION

The committee recommends that the Tentative Method of Test for Unsaponifiable Matter in Rosin (**D 1065 – 51 T**) be continued as tentative in view of the fact that collaborative work is still under way on an alternate method, as referred to under subcommittee activities.[2]

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[3]

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Softening Point of Rosin (J. M. Schantz, chairman).—This subcommittee is continuing to cooperate with the Task Group on Softening Point of Committee E-1 in its efforts to consolidate the ASTM Method of Test for Softening Point of Bituminous Materials (Ring-and-Ball Method) (D 36 – 26), and ASTM Method of Test for Softening Point by Ring and Ball Apparatus (E 28 – 51 T) into a single method.

Progress is reported in the adaptation or use of Method E 28 for testing synthetic resins that cannot be melted for pouring the ring sample, but must be powdered and pressed into the ring. Modification in the design of the ring and of the plunger press are under study. It has also been reported that improvements have been made in the electrically heated bar type of melting point apparatus, such as the Dennis-Parr bar. Any significant data or information on this subject will be brought to the attention of the committee.

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[1] 1952 Book of ASTM Standards, Part 4.

[2] See Editorial Note, p. 516.

[3] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

Subcommittee II on Crystallization of Rosin (S. R. Snider, chairman).—The conditions which may induce in rosin a tendency to throw out the rosin acids in crystal form are under study. Some preliminary experiments along new lines gave encouraging results.

Subcommittee IV on Chemical Analysis of Rosin (R. Herrlinger, chairman).—The subcommittee is continuing the collaborative analytical work on a modification of the previously proposed separatory funnel method for determining unsaponifiable matter in rosin. The present studies are based on the tests made by several collaborators last year. If favorable results are again obtained, it is proposed to incorporate this method as an alternate procedure in the present Tentative Method of Test for Unsaponifiable Matter in Rosin (D 1065 – 51 T). The need for an additional more rapid method which does not require specially designed extraction apparatus was pointed up by the discovery that a number of samples of gum rosin submitted to one of the collaborating laboratories for analysis as being representative of the gum rosin derived from a native foreign pine species growing in a producing country gave appreciably higher unsaponifiable content than is generally found in American gum rosin.

Subcommittee V on Tall Oil (A. Pollak, chairman) has been studying the applicability for testing whole tall oils by the new Tentative Method of Test for Rosin Acids in Fatty Acids (D 1240 – 52 T), developed primarily for the analysis of refined tall oils. Recommendation has been made for adoption of this tentative as standard. Additional work is under way on the Methods of Testing Tall Oil (D 803 – 51) for the purpose of improving the modified Wolff and the McNicholl procedures for esterifying the fatty acids in the determination of rosin acids in whole tall oil.

It has been reported that the time provided for the esterification step was not long enough and should be extended from 2 min to 5 min.

Recommendation for revising Method D 803, by incorporating improvements in the tests for rosin acids and unsaponifiable matter, will be submitted in the near future.

Subcommittee VII on Terpene Hydrocarbons and Pine Oil (R. E. Price, chairman).—Progress is being made by the E-1 Task Group on Distillation in clarifying the difficulties arising over the scope and use of the two ASTM distillation methods—Test for Distillation of Gasoline, Naphtha, Kerosine, and Similar Petroleum Products (D 86), and Test for Distillation Range of Lacquer Solvents and Diluents (D 1078). It has been proposed that Method D 86 be applied to those solvents and thinners having a spread of 10 C (18 F) or more between the 10 and 90 per cent distillate readings and that Method D 1078 be used only for solvents having a spread of less than 10 C between the 10 and 90 per cent distillate recovery readings. Under this differentiation, turpentine and related terpene hydrocarbon thinners will continue to come under the scope of Method D 86 since there is usually a spread of about 15 C between the 10 and 90 per cent distilling temperatures.

Subcommittee IX on Definitions (J. L. Boyer, chairman).—It has been suggested that the scope of the definition for dipentene should cover a wider and more detailed range, as is the case in the definitions for the various kinds of pine oils. Dipentene or a product so described is obtained in the refining of all kinds of crude wood turpentine, and the dipentene from sulfate wood turpentine seems to be enough different to warrant a more detailed definition for dipentene in general. The matter is being studied by the chairman of the subcommittee.

Subcommittee X on Specifications (S. R. Snider, chairman).—It has been decided to defer further action on preparation of ASTM specifications for rosin, pine oil, and other naval stores products (other than turpentine, for which standard specifications have been adopted) pending further consideration of the practicability of such specifications. Some members of the committee felt that naval stores products were manufactured in so many "tailored" qualities or grades, to suit individual consumer requirements, that the adoption of an ASTM specification for a single grade was not desirable and might result in confusion between producers and consumers of such materials. This decision was confirmed by letter ballot. The subcommittee will discontinue its work on specifications for naval stores products until further notice.

This report has been submitted to letter ballot of the committee, which consists of 37 voting members; 30 members returned their ballots, of whom 27 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

V. E. GROTLISCH,
Chairman.

W. A. KIRKLIN,
Secretary.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee D-17 presented to the Society through the Administrative Committee on Standards the recommendation that the Tentative Method of Test for Unsaponifiable Matter in Rosin (D 1065 – 51 T) be revised. This recommendation was accepted by the Standards Committee on November 5, 1954, and the revised method appears in the 1954 Supplement to Book of ASTM Standards, Part 4.

REPORT OF COMMITTEE D-18
ON
SOILS FOR ENGINEERING PURPOSES*

Committee D-18 on Soils for Engineering Purposes held its annual meeting at Atlantic City, N. J., on July 2, 1953. Executive Committee meetings were held on July 1, 1953, at Atlantic City, and on January 12, 1954, at Washington, D. C.

Two symposia were sponsored by Committee D-18 during the 1953 Annual Meeting of the Society. The first, entitled "Lateral Load Tests on Piles" (STP 154), occupied two sessions and consisted of seven papers with introductory and summary remarks. The second symposium, entitled "Dynamic Testing of Soils" (STP 156), also occupied two sessions and consisted of twelve papers and introductory remarks. All papers and discussions are being published by the Society as special technical publications.

The Board of Directors of the Society has approved the establishment of a C. A. Hogentogler Memorial Award by Committee D-18. This award will consist of a certificate and will be awarded to the author or authors of papers of outstanding merit on soils for engineering purposes which are presented at meetings of the Society. The purpose of this award is to stimulate research, to encourage the knowledge of soils for engineering purposes, and to recognize meritorious effort. The award is named in honor of the committee's first chairman who served from 1936 to 1937 and 1940 to 1944, and will not necessarily be made annually. The Executive Subcommittee authorized the establishment of a fund to defray the necessary expense connected with the initiation and continuance of the award. The fund will be raised by voluntary subscription of the committee members.

The death of E. N. McGee, member of the committee, was announced at the June meeting.

Committee D-18 now consists of a total of 125 individual members and 17 consultants. There are 97 voting memberships divided as follows: producers, 16; consumers, 41; and general interest members, 40.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, E. J. Kilcawley.
First Vice-Chairman, W. S. Housel.
Second Vice-Chairman, F. J. Converse.
Secretary, W. G. Holtz.
Assistant Secretary, A. A. Wagner.

REVISION OF STANDARDS AND REVERSION TO TENTATIVE

The committee recommends that the following standards be revised as appended hereto[1] and reverted to tentative status:

Methods of:

Test for Liquid Limit of Soils (**D 423 – 39**),[2]
Test for Plastic Limit and Plasticity Index of Soils (**D 424 – 39**),[2] and
Mechanical Analysis of Soils (**D 422 – 51**).[2]

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13–18, 1954.

[1] The proposed revisions were accepted by the Society and the methods as revised appear in the 1954 Supplement to Book of ASTM Standards, Part 3.

[2] 1952 Book of ASTM Standards, Part 3.

ADOPTION OF TENTATIVE AS STANDARD

The committee recommends that the Tentative Method of Test for Amount of Material in Soils Finer than the No. 200 Sieve (**D 1140 - 50 T**)[2] be approved for reference to letter ballot of the Society for adoption as a standard, with the following change:

Section 4(c).—Add the following note to this section:

NOTE.—The percentage value secured at the end of the test may not be correct (being too low) for soils containing relatively high percentages of the minus 200 fraction. This appears to be due chiefly to inadequate agitation. When it is desired to secure the exact percentage for the minus 200 fraction for such a soil, the portion of the sample passing the No. 40 sieve and retained on the No. 200 sieve secured in the washing operation, shall be transferred to the dispersion cup of the stirring apparatus used in the Standard Method of Mechanical Analysis of Soils (ASTM Designation: D 422); the cup filled half full with water and the contents agitated for 1 min. After this agitation the contents of the cup shall be transferred to the nested sieves and washing continued.

If the stirring apparatus has not been used prior to the drying of the portion of the sample larger than the No. 200 sieve, and it is desired to do so after drying, the dried material shall be separated on the No. 40 sieve; the portion retained shall be saved; and the portion passing shall be placed in the dispersion cup with water and agitated for 1 min with the stirring apparatus as previously described. The contents of the cup shall be transferred to the No. 200 sieve, washed, and dried. The revised total weight retained on the No. 200 sieve shall be secured by combining and weighing the two fractions.

TENTATIVES CONTINUED WITHOUT REVISION

The committee recommends that the following tentatives which have stood for two or more years without revision be continued as tentative without change:

Tentative Definitions of:

Terms and Symbols Relating to Soil Mechanics (D 653 - 42 T).

Tentative Methods of Test for:

Moisture-Density Relations of Soils (D 698 - 42 T),

Shear Strength of Flexible Road Surfaces, Subgrades, and Fills by the Burggraf Shear Apparatus (D 916 - 47 T),

Load-Settlement Relationship for Individual Piles (D 1143 - 50 T),

Bearing Capacity of Soil for Static Load on Spread Footings (D 1194 - 52 T),

Repetitive Static Load Tests of Soils for Use in Evaluation and Design of Airport and Highway Pavements (D 1195 - 52 T), and

Nonrepetitive Static Load Tests of Soils for Use in Evaluation and Design of Airport and Highway Pavements (D 1196 - 52 T).

Tentative Method of Testing:

Soil Bituminous Mixtures (D 915 - 47 T).

Tentative Specifications for:

Materials for Soil-Aggregate Sub-base, Base, and Surface Courses (D 1241 - 52 T).

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[3]

SUBCOMMITTEE ACTIVITIES

Subcommittee G-1, Editorial (E. E. Bauer, chairman) reviewed all of the standards upon which action was taken in the committee during the year.

Subcommittee G-2 on Special Papers (C. H. Shepard, chairman) reviewed four special papers for presentation at the June, 1954, meeting.

Subcommittee G-3 on Nomenclature and Definitions (C. R. Foster, chairman) has been engaged in the task of reviewing 600 terms prepared by a parallel committee of the American Society of Civil Engineers. Compilations of the definitions are in progress, and after completion they will be discussed with the parallel A.S.C.E. committee in an effort to reach agreement on the definitions.

Subcommittee R-2 on Sampling and

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[3] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

Related Field Testing for Soil Investigation (J. O. Osterberg, chairman).—Work has been continued on the development of standards for the auger sampling, split spoon sampling, and Shelby tube sampling of soils.

Subcommittee R-3 on Physical Characteristics of Soils (Harold Allen, chairman).—The subcommittee prepared the revisions of Tentative Methods D 423, D 424, and D 422, referred to earlier in the report. The subcommittee is working on revisions of the Tentative Method of Test for Moisture-Density Relations of Soils (D 698 – 42 T).

Subcommittee R-4 on Physical Properties of Soils (E. S. Barber, chairman) has been arranging for a Symposium on Permeability of Soils for the 1954 Annual Meeting of the Society.[4] After this symposium, activity will resume on permeability test standards.

Subcommittee R-7 on Identification and Classification of Soils (A. A. Wagner, chairman).—Through Subcommittee G-3 agreement has been reached on a proposed list and descriptions of soil components. A review of the 1950 symposium and other classification systems not contained therein will be made toward the development of standards on soil classification

Subcommittee R-8 on Special and Construction Control Tests (H. F. Clemmer, chairman) has made progress in the preparation of methods of test for the California Bearing Ratio, the Burggraf shear test, the moisture-density relation of soils, and tests on bituminous mixtures. The soil-cement section is considering two test methods for determination of cement content which may be specified as alternates for the present method. In addition, the subcommittee has submitted a method of test for determining chlorides in soils and recommended changes in the gradation requirements for soils material for surfaces and base courses.

Subcommittee R-9 on Dynamic Properties of Soils (R. K. Bernhard, chairman).—Most of the activities of this subcommittee centered around the Symposium on Dynamic Testing of Soils. The publication of the twelve symposium papers presented at the 1953 Annual Meeting and a bibliography is now in process as Special Technical Publication (STP) No. 156. A glossary of terms relating to soil dynamics will be prepared.

Subcommittee R-10 on Bearing Tests of Soil in Place (L. A. Palmer, chairman.—In 1953 the subcommittee sponsored the Symposium on Lateral Load Tests on Piles, now published as Special Technical Publication (STP) No. 154. The symposium was planned to provide the subcommittee with material from which it might work out a lateral load test procedure similar to the procedure for vertical load tests covered by Method D 1143 – 50 T. The subcommittee expects to study this problem.

This report has been submitted to letter ballot of the committee, which consists of 97 voting members; 76 members returned their ballots, of whom 73 voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

E. J. KILCAWLEY,
Chairman.

W. G. HOLTZ,
Secretary.

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[4] Issued as separate publication *ASTM STP No. 163.*

REPORT OF COMMITTEE D-19
ON
INDUSTRIAL WATER*

Committee D-19 on Industrial Water and all of its subdivisions held meetings on June 29, July 1 and 2, 1953, in Atlantic City, N. J., and on February 3 to 5, 1954, in Washington, D. C.

A paper entitled "A Comparison of Methods of Testing for Dissolved Oxygen in Waters of High Purity," by W. L. Riedel, was presented on July 1, 1953, at a session of the Annual Meeting.[1] The paper reported the results secured at the Dissolved Oxygen Clinic, held during July, 1952, under the sponsorship of Subcommittee IV on Methods of Analysis.

Recommendations relative to the Manual on Industrial Water, STP No. 148, January, 1953, have been submitted to the Society. The recommendations cover the inclusion in the second printing of the first edition of a subject index, the alphabetical and numerical listing of the methods in the Table of Contents, and the addition of all of the methods of the committee accepted through December, 1953. This second printing is expected to be ready later in the year.[2]

The proposals for the reorganization of the structure of Committee D-19 on Industrial Water have been returned to the task group of origin for restudy.

The committee has accepted by letter ballot vote the Rules for the Committee D-19 Achievement Award (Max Hecht Award) issued August 1, 1953.

Members of the committee appointed as liaison representatives by the Society to serve on committees of other organizations[3] have filed reports of activities with Society Headquarters.

The committee officers elected by virtue of the letter ballot vote on this report, to serve the two-year term starting July 1, 1954, are as follows:

Chairman, Max Hecht.
Vice-Chairman, R. C. Adams.
Vice-Chairman, F. R. Owens.
Secretary, O. M. Elliott.

At present, the committee numbers 117 members.

RECOMMENDATIONS ACCEPTED BY THE ADMINISTRATIVE COMMITTEE ON STANDARDS

Subsequent to the 1953 Annual Meeting, Committee D-19 presented to the Society through the Administrative Committee on Standards the following recommendations:

Tentative Method of:

Test for Chlorine Requirements of Industrial Water and Industrial Waste Water (D 1291 – 53 T),
Test for Odor of Industrial Waste Water (D 1292 – 53 T), and
Determination of pH of Industrial Waste Water (D 1293 – 53 T).

These recommendations were accepted

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13–18, 1954.

[1] *Proceedings*, Am. Soc. Testing Mats., Vol. 53, p. 1103 (1953).

[2] Issued as separate publication *ASTM STP No. 148-A*.

[3] The organizations and the representatives are published in the 1953 ASTM Year Book, p. 509.

by the Standards Committee on September 9, 1953, and the tentative methods appear in the 1953 Supplement to Book of ASTM Standards, Part 7.

PROPOSED METHODS FOR PUBLICATION AS INFORMATION

The committee submits the following five new proposed methods with the recommendation for publication as information as appended hereto:

Method of Test for Hardness of Industrial Water,

Method of Test for Hydroxide Ion in Industrial Water,

Method of Test for Nitrate Ion in Industrial Water,

Method of Test for Sulfite Ion in Industrial Water,

Method of Test for the Evaluation of the Acute Toxicity of Industrial Waste to Fresh Water Fishes.

The first four methods were prepared by Subcommittee IV and appear as Appendix II[4]; the fifth was prepared by Subcommittee VII, and appears as Appendix III.[5]

NEW TENTATIVES

The committee recommends the following three new proposed methods for publication as tentative as appended hereto:[6]

Method of Test for Sulfite Ion in Industrial Water, prepared by Subcommittee IV,

Method for the Measurement of the Thickness of Deposits on the Internal Tubular Surfaces of Heat Exchangers, prepared by Subcommittee VI, and

Method of Test for Oily Matter in Industrial Water, prepared by Subcommittee VII.

Supporting data for the Method of Test for Oily Matter is given in the Appendix to this report.[7]

REVISION OF TENTATIVES

The committee recommends that the following five methods be revised as indicated and continued as tentative:

Tentative Methods of Test for Total Carbon Dioxide and Calculation of the Carbonate and Bicarbonate Ions in Industrial Water (**D 513 – 50 T**).[8]—Completely revised by Subcommittee IV as appended hereto.[9]

Supporting data for the revised methods of test for total carbon dioxide is given in the Appendix to this report.[7]

Tentative Methods of Test for Suspended and Dissolved Solids in Industrial Water (**D 1069 – 49 T**).[8]– Completely revised by Subcommittees IV and VII as appended hereto.[9]

Tentative Methods of Sampling Industrial Water (**D 510 – 52 T**).[8]—Revised as follows as recommended by Subcommittee III:

Section 1 (*a*).—Change to read as follows:

(*a*) These methods cover the sampling of industrial water for physical, chemical, or biological tests.

Retain the present Footnote 3.

Section 27 (*e*).—Add a paragraph *e* as follows:

> (*e*) When the water to be sampled is confined at low or subatmospheric pressure, special means must be provided to extract the sample. The simplest arrangement, where physical conditions permit, is the installation of a barometric leg. A second method may consist of a small pump[a] arranged to discharge into the sampling container at atmospheric pressure. The pump should be of such material and construction that the sample will not be contaminated. The sample receiver may also be located between the pump and the sampling
>
> [a] Two commercially available pumps that appear to be suitable for this service are the "Sigma Motor" and the "Vanton."

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[4] The proposed methods appear in the September, 1954, printing of the Manual on Industrial Water. (Issued as separate publication *ASTM STP No. 148-A.*)

[5] The proposed method was subsequently recommended for publication as tentative through the Administrative Committee on Standards and appears in the 1954 Supplement to Book of ASTM Standards, Part 7, as well as in the September, 1954, printing of the Manual on Industrial Water. (Issued as separate publication *ASTM STP No. 148-A.*) See Editorial Note, p. 526.

[6] The new methods were accepted by the Society and appear in the 1954 Supplement to Book of ASTM Standards, Part 7.

[7] See p. 527.

[8] 1952 Book of ASTM Standards, Part 7.

[9] The revised methods were accepted by the Society and appear in the 1954 Supplement to Book of ASTM Standards, Part 7.

point. With this arrangement, the receiver must be valved off, equalized to atmospheric pressure, and drained into a container.

Tentative Methods of Sampling Steam (**D 1066 - 49 T**).[8]—Revisions are appended hereto.[10]

Tentative Method of Test for Chloroform-Extractable Matter in Industrial Water (**D 1178 - 51 T**).[8]—Revised as follows as recommended by Subcommittee IV:

Title.—Change to read "Tentative Method of Test for Chloroform-Extractable Matter in Industrial Water and Industrial Waste Water."

Section 1.—Change to read as follows:

1. *Scope and Application.*—(*a*) This method covers the separation of chloroform-extractable matter from industrial water and industrial waste water, and the gravimetric determination of that portion of the extract which is not lost upon evaporation of the chloroform. This residue may contain one or more members of several classes of compounds, among which are heavy oils and fats, trace amounts of phenols, rubber and certain resins, asphaltenes and carbenes, and decomposition products of tannin.

(*b*) This method is applicable to the determination of heavy oils in industrial water and industrial waste water. It is not intended to determine materials that volatilize under the conditions of test nor to determine specific oils, greases, and organic compounds. When such information is desired, the residue obtained by this method may be subjected to further extraction with specific solvents agreed upon by the interested parties.

Retain the present Footnote 3.

REVISION OF STANDARD AND REVERSION TO TENTATIVE

The committee recommends revisions of the Standard Method of Reporting Results of Analysis of Industrial Water (**D 596 - 49**)[8] as appended hereto[10] with the recommendation that the method be published as tentative and the standard method withdrawn.

ADOPTION OF TENTATIVE AS STANDARD

The committee recommends that the Tentative Method of Sampling Water from Boilers (**D 860 - 51 T**)[8] be adopted as standard without change, on the recommendation of Subcommittee III.

REVISION OF STANDARD, IMMEDIATE ADOPTION

The committee recommends for immediate adoption the following revisions of the Standard Definitions of Terms Relating to Industrial Water (**D 1129 - 53**)[11] and accordingly asks for a nine-tenths affirmative vote at the Annual Meeting in order that the revisions may be referred to letter ballot of the Society:

In Part I of these definitions, add a new definition for "part per billion" and change the present definitions for "dissolved matter," "suspended matter," and "total matter" to read as follows:

Part per Billion (*ppb*).—A measure of proportion by weight, equivalent to a unit weight of solute per billion (10^9) unit weights of solution. (D 596)

NOTE.—A part per billion is generally considered equivalent to one millionth of a gram per liter, but this is not precise. A part per billion is equivalent to a milligram of solute per one thousand kilograms of solution.

Dissolved Matter (*Dissolved Solids*).—The dried residue from evaporation of the filtrate after separation of suspended matter (suspended solids). (D 1069)

Suspended Matter (*Suspended Solids*).—That matter (those solids) which can be separated from the sample by filtration. (D 1069)

Total Matter (*Total Solids*).—The sum of the suspended and dissolved matter (solids). (D 1069)

In Part IV of these definitions, revise the title by changing "Water Borne Industrial Wastes" to read "Industrial Waste Water," and add the following new definitions:

Chlorine Requirement.—The amount of chlorine, expressed in parts per million, required to achieve under specified conditions the objectives of chlorination. (D 1291)

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[10] The proposed revisions were accepted by the Society and the methods as revised appear in the 1954 Supplement to Book of ASTM Standards, Part 7.

[11] 1953 Supplement to Book of ASTM Standards, Part 7.

Floating Matter.—That matter which passes through a No. 10 (2000-micron) sieve and which can be separated by flotation for 1 hr. (D 1069)

Ignited Matter (*Fixed Solids*).—Residue remaining after ignition of suspended matter or dissolved matter at 600 ± 25 C for 30 min. (D 1069)

Non-Oily Suspended Matter.—That suspended matter which remains as residue after extraction by benzene or chloroform. (D 1069)

Nonsettleable Matter.—That matter which passes through a No. 10 (2000-micron) sieve and does not float to the surface or settle in a period of 1 hr. (D 1069)

Oily Matter.—Hydrocarbons, hydrocarbon derivatives, and all liquid or unctuous substances that have boiling points of 90 C or above and are extractable from water at pH 5.0 or lower, using benzene as a solvent.

NOTE.—Chloroform or carbon tetrachloride may be substituted for benzene to avoid fire hazard or emulsion difficulties. The oily matter extracted by these solvents is, for practical purposes, the same material as that extracted by benzene.

Settleable Matter.—That matter which passes through a No. 10 (2000-micron) sieve and which can be separated by sedimentation for 1 hr. (D 1069)

Volatile Matter.—Apparent loss of suspended matter or dissolved matter due to ignition at 600 ± 25 C for 30 min. (D 1069)

TENTATIVES CONTINUED WITHOUT REVISION

The committee recommends that the following be continued as tentative without revision as recommended by Subcommittee IV:

Tentative Methods of:

Test for Silica in Industrial Water (**D 859 - 50 T**),
Test for Dissolved Oxygen in Industrial Water (**D 888 - 49 T**),
Test for Acidity and Alkalinity in Industrial Water (**D 1067 - 51 T**),
Test for Iron in Industrial Water (**D 1068 - 49 T**),
Test for Electrical Conductivity of Industrial Water (**D 1125 - 50 T**),
Test for Sodium and Potassium in Industrial Water (**D 1127 - 50 T**),
Identification of Types of Microorganisms in Industrial Water (**D 1128 - 50 T**),
Test for Fluoride Ion in Industrial Water (**D 1179 - 51 T**),
Examination of Water-Formed Deposits by Chemical Microscopy (**D 1245 - 52 T**), and
Test for Iodide and Bromide Ions in Industrial Water (**D 1246 - 52 T**).

Tentative Specifications for:

Equipment for Sampling Industrial Water and Steam (**D 1192 - 51 T**), and
Reagent Water (**D 1193 - 52 T**).

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I, Advisory (Max Hecht, chairman).—In addition to the preparation of a subject index of the Manual on Industrial Water, the Advisory Committee has recommended to Subcommittee II a long range project consisting of a study for a proposed expansion of the contents of the Manual, by the revisions of existing chapters or additional new ones, or both, to cover material pertinent to industrial waste water.

The committee approved two policies at its February 5 meeting, which provide for improvement of the administration of the committee and the operation of the subdivisions.

1. It approved the use of condensed tabulated schedules of meetings prepared for the February meetings, with the following changes:

The task group meetings are to be scheduled by the respective subcommittee chairmen to reduce conflicts to a minimum.

2. In instances where more than one task group has been directed to prepare methods for similar ions or substances, the subcommittee chairmen concerned are directed to establish by agreement a task group in one subcommittee. The members of the single task group are to be those committee members serving as cooperators in the preparation of the method. This policy is, in effect, a reaffirmation of the subject covered in

Section 3, Article A, Part III, of the Guide for the Administration and Operation of Committee D-19 (1952). This coordination is to be made effective at the onset of and during the preparation of the method, when more than one subcommittee has equal interests in the method.

The Board of Directors approved in September, 1953 the rules for the Committee D-19 Achievement Award. It directed that the name be altered to read "Max Hecht Award." The rules, together with those of other committees, will be published by the Society in pamphlet form.

An Awards Nominations Task Group has been appointed consisting of David Milne, term expiring June 30, 1955; A. A. Berk, term expiring June 30, 1956; and G. F. Wiest, term expiring June 30, 1957. The senior member will serve as chairman and a replacement will be made each year for a three-year term.

Effective June 30, 1954, Eli Mandel resigned as Secretary of Subcommittee III, and B. W. Dickerson, as Secretary of Committee D-19. A. O. Walker was appointed to the subcommittee effective July 1, 1953, and J. K. Rice was added to the subcommittee February 3, 1954, as Secretary of Subcommittee VI.

The following appointments have been accepted to serve on the Informal Task Group to Secure Uniformity of Methods for the Examination of Water: Gail P. Edwards, Chairman, Standard Methods of Sewage and Industrial Waste Analysis, of the Federation of Sewage and Industrial Waste Associations, and John E. Kinney, of the Ohio River Valley Water Sanitation Commission.

Subcommittee II on Definitions and General Specifications (S. K. Love, chairman): Section A, Manual (R. D. Hoak, chairman) completed the preparation of an index for inclusion in the second edition scheduled for early publication.[2] There will also be included those methods approved and released by the Society subsequent to publication of the first edition. Plans are proceeding for revision and expansion of the Manual to include a discussion of industrial wastes. Although not definitely determined, it is hoped that the expanded Manual will be ready for publication in 1956.

Section B on Terminology and Nomenclature (R. E. Price, chairman) reviewed and approved definitions included in methods recently published by the Society and in methods approved for publication. The section accepted an assignment for developing acceptable definitions for precision and accuracy.

Section D (R. J. Austin, chairman), in cooperation with Section D of Subcommittee VII, undertook the revision of Method D 596 on reporting results of analysis of industrial water. The revised method will include waste water.

Subcommittee III on Methods of Sampling (O. M. Elliott, chairman).—The subcommittee recommended:

The adoption as standard of the Tentative Method of Sampling of Water from Boilers (D 860 – 51 T), without revision,

The revision of the Tentative Method of Sampling of Industrial Water (D 510 – 52 T), the revision to include added sections covering the sampling of water at subatmospheric pressure, and

The revision of the Tentative Method of Sampling of Steam (D 1066 – 49 T), the revision to add sections describing the sampling of steam at subatmospheric pressure with illustrations of the apparatus.

Subcommittee IV on Methods of Analysis (Frank E. Clarke, chairman) has prepared revisions of the Tentative Methods of Test for Carbon Dioxide in Industrial Water and for Chloroform Extractable Matter in Industrial Water.

Special adaptations of existing, or proposed, ASTM non-referee methods of test for hardness, hydroxide, nitrate, and sulfite in industrial water have been prepared for prospective use in Appendix 7 of the ASME "Suggested Care of Power Boilers."

Section A, Analytical (Frank E. Clarke, chairman) reported progress in preparation of new and revised methods for organic carbon by dichromate oxidation, dissolved oxygen, phosphate, ammonia by both distillation and straight colorimetric techniques, sulfate by turbidimetry, sulfite, dissolved hydrogen, fluoride, sulfide, turbidity and color, and suspended and dissolved solids. The last three are joint tasks with Subcommittee VII. The work on dissolved oxygen will include two elaborate test clinics for evaluation of relative accuracies of several methods.

Section B, Electrometric Methods (R. Rosenthal, chairman) has completed a final draft of method for measurement of oxidation-reduction characteristics of industrial waters and waste waters. This soon will be circulated for letter ballot of the committee.

Section C, Instrumental Methods (A. O. Walker, chairman) has made progress in preparing methods for flame photometric measurement of sodium and potassium and optical spectroscopic examination of water deposits. A new task group has been established to develop methods for surface tension measurements on industrial water and industrial waste water.

Section D, Analysis of Deposits (F. U. Neat, chairman) has completed a new proposed scheme for deposit analysis. Cooperating laboratories will test this scheme on a master deposit to be provided by the chairman.

Subcommittee VI on Corrosivity Testing (Frank W. Alquist, chairman) reports material progress on two projects. Two new projects were planned at the February meeting.

The Task Group on the Determination of Thickness of Internal Deposits on Tubular Heat Exchange Surfaces has completed the work on this project for inclusion in the Report of Committee D-19.

The Task Group on Service Testing of Tubular Metallic Materials has redesigned the test apparatus and is continuing its testing. The subcommittee desired cooperation in securing detailed data on the chemical composition and the identification of water-formed deposits to supplement the photographic record of the deposits.

A new task group is being formed to set up testing procedures for ion exchange resins used for industrial water.

The Task Group on Radioactivity Testing has a new project—the use of radioactive tracers in testing of hydraulic characteristics of gravity separators.

Subcommittee VII on Industrial Waste Water (L. Drew Betz, chairman) polled the membership relative to the absorption of Subcommittee VII into the other Subcommittees of Committee D-19. The poll indicated that a majority of the members expressing opinion did not favor such a move. Consequently, the matter was referred back to Committee D-19 with the suggestion that the matter be returned to the Task Group studying the proposed revision of D-19 structure.

The scope of Subcommittee VII has been changed to include the word "Gaging." The scope of Subcommittee VII now reads: "This Subcommittee shall prepare methods of sampling, gaging, and testing for constituents of industrial waste water, preservation of samples, and recording of results."

Section A on Critical Constituents of Industrial Waste Water has found it impractical to set critical constituents in various industrial waste waters. Accordingly, this section has been dissolved and the information compiled to date will be turned over to Subcommittee II which is working on revision of the Manual.

Section B on Analytical Methods (R. F. Weston, chairman) has completed the method of Suspended and Dissolved Solids. The method on toxicity to aquatic life has also been prepared and is recommended for publication, as information only.[5] The methods on pH and odor are being advanced from "information only" status to a "tentative" status. A method on chlorine requirements has also been developed.

Section C on Gaging and Sampling of Industrial Waste Water has been reorganized with J. B. Smith as new chairman.

Section D on Reporting Analysis of Industrial Waste Water (W. W. Hodge, chairman) has recommended that the Suggested General System for Reporting Test Data on Industrial Waste Water, which was published as information only with the 1952 Report of Committee D-19, be referred to Subcommittee II for consolidation in a revision of Method D 596, Reporting Results of Analysis of Industrial Water, with a change of title to include "Waste Water."

This report has been submitted to letter ballot of the committee, which consists of 117 members; 68 members returned their ballots, of whom 63 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

MAX HECHT,
Chairman.

BRUCE W. DICKERSON,
Secretary.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee D-19 presented to the Society through the Administrative Committee on Standards the Tentative Method of Test for the Evaluation of the Acute Toxicity of Industrial Waste Water to Fresh Water Fishes. The method was accepted by the Standards Committee on September 28, 1954, and it appears in the 1954 Supplement to Book of ASTM Standards, Part 7, bearing the designation D 1345 – 54 T.

APPENDIX

SUPPORTING DATA RELATING TO NEW AND REVISED METHODS OF TESTING INDUSTRIAL WATER AND INDUSTRIAL WASTE WATER

Supporting data relating to the new and revised methods for industrial water and industrial waste water, included in the Report of Committee D-19, are given in this Appendix.

Supporting Data Relating to the Proposed Tentative Method of Test for Oily Matter in Industrial Waste Water

Data obtained in the evaluation of this method are presented in Table I. Data obtained on oily matter boiling above 300 F, by omitting the preliminary distillation and starting with the extraction, are presented in Table II.[1]

TABLE I.—DETERMINATION OF OILY MATTER IN INDUSTRIAL WASTE WATER.

Oily Matter Added	Oily Matter Added, ppm	Oily Matter Recovered, ppm	Percentage Recovery
⅓ SAE 70 oil plus ⅓ kerosene plus ⅓ gasoline.......	10	8.6	86
	10	9.0	90
	10	9.1	91
	10	9.0	90
	10	8.3	83
	75	75.6	101
	75	70.4	94
	75	71.0	95
	75	72.5	97
	75	69.9	93
	150	144	96
	150	147	98
	150	140	93
	150	150	100
	150	149	99

TABLE II.—DETERMINATION OF OILY MATTER BOILING ABOVE 300 F IN INDUSTRIAL WASTE WATER.

Oily Matter Added	Oily Matter Added, ppm	Oily Matter Recovered, ppm	Percentage Recovery
⅔ SAE 70 oil plus ⅓ kerosene...	37.5	40.5	107
	47.2	49.3	104
	52.1	54.9	105
	52.1	57.5	110
	54.2	57.0	105
	54.3	59.0	108
	54.3	51.7	95
	80.7	80.9	99
Average......................			104.4
Mean deviation from known......			5.5
Maximum deviation from known...			10

Supporting Data Relating to the Proposed Revised Tentative Methods of Test for Carbon Dioxide and Calculation of the Carbonate and Bicarbonate Ions in Industrial Water

Data showing the effects of various interferences, as determined from test on the Proposed Non-Referee Method for Total Carbon Dioxide, are given in Table III.

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[1] A. F. S. Musante, "Determination of Oil in Refinery Waters," *Analytical Chemistry*, Vol. 23, pp. 1374–1379 (1951).

TABLE III.—INTERFERENCE OF PHOSPHATES, SILICATES, IRON, ALUMINUM, AND MAGNESIUM WITH THE DETERMINATION OF TOTAL CARBON DIOXIDE IN WATER.

Sample	CO_2 Present	Interference Present, ppm						CO_2 Found, ppm
		PO_4[a]	SiO_2[a]	Fe[a]	Al[b]	Mg[c]	NH_4Cl	
A	20.15	...	...	...	...	...	...	21.0 (Average of 10)
B	26.0	...	...	...	...	...	...	27.0 (Average of 10)
C	46.5	...	...	...	...	...	...	46.5 (Average of 10)
D	9.0	...	...	...	...	...	...	9.0, 9.5, 9.5, 8.0, 11.0
E	10.5	...	...	...	...	...	...	9.5, 11.0, 10.0
F	59.0	200	...	...	...	...	...	56
G	52.0	200	...	...	...	...	...	53, 52, 50, 52, 51.5
H	52.0	...	50	...	...	...	...	55, 53, 51, 52
I	52.0	...	...	...	25	...	...	56, 53, 54, 53
J	52.0	...	...	50	...	...	...	51, 52, 54, 49, 51.5
K	52.0	...	...	...	...	25	...	55, 54, 53, 52
L	52.0	...	...	...	...	...	...	51.5, 51.5
M	10.5	200	...	...	...	...	...	11.5, 11.0
N	10.5	...	50	...	...	...	...	9.0, 10.0
O	10.5	...	...	50	...	...	...	9.5, 10.0
P	10.5	...	...	...	25	...	...	8.5, 9.5
Q	10.5	...	...	...	...	25	...	12.0, 10.0
T	47.0	...	...	...	...	...	26	47
T	47.0	...	...	...	...	...	26	47
T	47.0	...	...	...	...	...	26	46

[a] PO_4, SiO_2, and Fe afforded no great difficulty.

[b] The presence of 25 ppm Al tended to result in an elusive end point during the preliminary titration with 0.04 *N* HCl.

[c] The presence of Mg resulted in a fading end point. If the titration is carried out very carefully and slowly to an end point that remains for 1 min, good results can be obtained.

REPORT OF COMMITTEE D-20
ON
PLASTICS*

Committee D-20 on Plastics, and its subcommittees, held three meetings during the year: at Atlantic City, N. J., on June 30 to July 2, 1953; on September 28 to 30, 1953; and at Roanoke, Va., on March 22 to 24, 1954. The Advisory Committee also met at these times.

Committee D-20 continues to participate in the work of Technical Committee 61 of the International Organization for Standardization (ISO), the American Group for which has been set up under Committee D-20 with representation from the other interested groups. A number of representatives from this country attended the last meeting of ISO/TC 61 which was held in Stockholm, Sweden, on August 10 to 14, 1953. At that meeting several proposed test methods were approved for circulation to member nations for comment or approval, many of them adaptations of ASTM standards. G. M. Kline served as meeting chairman, and Robert Burns, chairman of the American Group, was leader of the American delegation. Close liaison is being developed between ISO/TC 61 and Technical Committee 15 of the International Electrotechnical Commission.

The next meeting of ISO/TC 61 is scheduled for October 4 to 8, 1954, in Brighton, England.

Committee D-20 has concentrated its attentions for the most part on specifications for the basic materials; its work is now being extended to include engineering products, and in order to point up this work more effectively and to bring in the work on reinforced plastics and plastic pipe as well, there are being set up five subcommittees in place of the present Subcommittee VI on Specifications, as follows:

Subcommittee XV on Thermoplastic Materials.

Subcommittee XVI on Thermosetting Materials.

Subcommittee XVII on Plastic Pipe and Fittings, functioning as a Joint Committee of the ASTM and the Society of the Plastics Industy.

Subcommittee XVIII on Reinforced Plastics.

Subcommittee XIX on Plastic Film and Sheeting.

At the spring meeting of the committee, the following officers were elected for the ensuing two-year term:

Chairman, R. K. Witt.

First Vice-Chairman, W. A. Zinzow.

Second Vice-Chairman, F. W. Reinhart.

General Secretary, G. M. Armstrong.

Membership Secretary, B. L. Lewis.

The following subcommittee chairmen were newly appointed: I. L. Hopkins, to Subcommittee VIII on Research; F. Y. Speight, to Subcommittee X on Definitions, Nomenclature, and Significance of Tests; and G. H. Mains, to Subcommittee XIV on Conditioning.

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13–18, 1954.

RECOMMENDATIONS ACCEPTED BY THE ADMINISTRATIVE COMMITTEE ON STANDARDS

Subsequent to the 1953 Annual Meeting, Committee D-20 presented to the Society through the Administrative Committee on Standards the following recommendations:

Tentative Specifications and Methods of Test for:

Laminated Thermosetting Decorative Sheets (D 1300 – 53 T).

Tentative Method of Test for:

Shrinkage of Molded and Laminated Thermosetting Plastics at Elevated Temperature (D 1299 – 53 T), and

Total Chlorine in Vinyl Chloride Polymers and Copolymers (D 1303 – 53 T).

Revision of Tentative Definitions of:

Terms Relating to Plastics (D 883 – 53 T).

The new tentatives D 1299 and D 1300 were accepted by the Standards Committee on September 9, 1953; the new tentative D 1303 and the revision of tentative D 883 were accepted on December 16, 1953. With the exception of Method D 1300, these tentatives appear in the 1953 Supplement to Book of ASTM Standards, Part 6. Methods D 1300 appear in the 1954 Supplement to Book of ASTM Standards, Part 6.

RECOMMENDATIONS AFFECTING STANDARDS

The committee is recommending the revision of 7 tentatives, the revision and reversion to tentative of 2 standards, the adoption as standards of 6 tentatives, the adoption as standards of 2 tentative revisions of standards, the revision of 1 standard for immediate adoption, and the withdrawal of 3 tentatives. The standards and tentatives affected, together with the revisions recommended, are given in detail in the Appendix.[1]

The committee has considered all of the other tentatives, not mentioned in the Appendix, which are under its jurisdiction and which have been issued for two years or longer, and recommends that they be continued in their present status until further revisions in them are made as contemplated.

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[2]

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Strength Properties (R. M. Berg, chairman).—Revisions of the Tentative Methods of Test for Impact Resistance of Plastics and Electrical Insulating Materials (D 256 – 47 T) have been completed and are presented in this report. Revisions of the Tentative Methods of Test for Tensile Properties of Plastics (D 638 – 52 T), for Tensile Properties of Thin Plastic Sheets and Film (D 882 – 49 T),[2a] and for Tear Resistance of Plastic Film and Sheeting (D 1004 – 49 T) are under way. Methods of test for measuring stiffness of film and for bursting strength of plastic pipe are being developed. Work on a method for measurement of dynamic modulus and on impact tests not included in Methods D 256 is in progress.

Subcommittee II on Hardness (H. L. McChesney, chairman).—A revision of the Tentative Method of Test for Resistance to Abrasion (Optical Effects) of Transparent Plastics (D 1044 – 49 T) has been completed as submitted in this report. A round-robin test program on blocking resistance is in progress.

Subcommittee III on Thermal Properties (C. H. Adams, chairman).—Methods for measuring flammability of plastic films and thin sheet are being studied. A round-robin test program on a proposed method for measuring melt viscosity by means of a parallel plate plastometer is in progress, and one on a method for heat distortion of thin films is being prepared. A method for heat-distortion temperature of thermosetting materials is being developed. Revisions of the Standard Methods of Test for Molding Index of Thermosetting Molding Powder (D 731 – 50) and for Brittleness Temperature of Elastomers (D 746 – 52 T) have been completed as submitted in this report. Resolution of differences among various kinds of commercial machines for measuring brittleness temperature is under study, and a method for brittle point of thin films is being prepared. Development of methods for measuring thermal conductivity and for measuring stress-relaxation properties is being considered.

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[1] See p. 534.

[2] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

[2a] See Editorial Note, p. 533.

Subcommittee IV on Optical Properties (H. K. Hammond, III, chairman).—Methods for measurement of small color differences are being prepared as a result of cooperative testing programs of Subcommittee X on Optical Properties, of Committee D-1 on Paint, Varnish, Lacquer, and Related Products, in which this subcommittee is participating. Preparation of haze standards for use with the Standard Method of Test for Haze and Luminous Transmittance of Transparent Plastics (D 1003 – 52) is continuing The subcommittee is also cooperating with Subcommittee III of Committee E-12 on Appearance in development of methods for reflectance and transmittance measurements, and for goniophotometric measurements.

Subcommittee V on Permanence Properties (J. W. Mighton, chairman).—Study of improved standardization of carbon-arc laboratory aging apparatus is in progress, and revisions of the Standard Methods of Test for Colorfastness of Plastics to Light (D 620 – 49) and for Accelerated Weathering of Plastics (D 745 – 49), to provide more readily available apparatus, are under study. A revision of the Standard Method of Test for Water Absorption of Plastics (D 570 – 42) has been completed and further revision is contemplated. A round-robin test program to compare differences in shrinkage of thermosetting plastics due to different specimen shapes is being carried on. Development of a method for measuring gas transmission, and preparation of a recommended practice for outdoor exposure testing, is in progress.

Subcommittee VI on Specifications (Lucius Gilman, chairman).—Work on the revision of the Tentative Specifications for Phenolic Molding Compounds (D 700 – 52 T) to include rubber-modified phenolics is continuing. Revisions of Standard Specifications for Cast Methacrylate Sheets, Rods, Tubes, and Shapes (D 702 – 46) and for Methacrylate Molding Compounds (D 788 – 52 T) are in progress, as well as a revision of the Tentative Specifications for Polystyrene Molding Compounds (D 703 – 52 T). Further revision of the Tentative Specifications for Vinyl Chloride Polymer and Copolymer Rigid Sheets (D 708 – 53 T), to include additional types and grades, has been initiated; revisions aimed toward eventual combination of the two Tentative Specifications for Nonrigid Vinyl Chloride-Acetate Resin Plastics (D 742 – 46 T) and for Nonrigid Vinyl Chloride Plastics (D 744 – 49 T) are in progress. Among other specifications currently being revised are those for molding compounds of urea-formaldehyde, melamine-formaldehyde, cellulose acetate, cellulose acetate-butyrate, ethyl cellulose, polyesters, and polyethylene, and for laminated thermosetting materials. Specifications for styrene-rubber thermoplastic molding compounds and for halocarbon plastics are being developed.

The subcommittee has now been discharged and is being reorganized into five new subcommittees as described earlier in this report, and its current activities will be reassigned to the appropriate new subcommittees. The final meeting of this subcommittee was held on March 24, 1953, at Roanoke, Va.

Subcommittee VII on Analytical Methods (H. E. Riley, chairman).—The Standard Methods of Test for Short-Time Stability at Elevated Temperatures of Plastics Containing Chlorine (D 793 – 49) and for Ammonia in Phenol-Formaldehyde Molded Materials (D 834 – 49) are being considered for revision. Methods for estimating volatile content, determining particle size, and measuring plasticity and plasticizer absorption of vinyl resins are in preparation. Work is being discontinued on development of a heat stability method for plasticizers.

Subcommittee VIII on Research (I. L. Hopkins, chairman).—In addition to serving in an advisory capacity on research problems, this subcommittee has continued to arrange for presentation of papers at its meetings. At the September, 1953, meeting at Atlantic City, N. J., the following four papers were presented:

"The Control of Weight Uniformity in Glass Mat by Statistical Methods," by G. E. Power of The Formica Co.

"Prediction of Deflection and Stress Distribution in Beams of Plastics which Creep," by W. N. Findley of the University of Illinois.

"Measurement of Particle Size Distribution in Vinyl Chloride Resins," by R. M. Berg and W. G. Best of Carbide and Carbon Chemicals Division, Union Carbide and Carbon Corp.

"The Potassium Permanganate Test as Applied to Tricresyl Phosphate," by J. E. Caldwell and L. Fowler of Monsanto Chemical Co.[3]

At the March, 1954, meeting, three papers and a panel discussion were presented, as follows:

"Fluorescent Sunlamps in Laboratory Aging Tests for Plastics," by F. W. Reinhart of the National Bureau of Standards.

Panel Discussion on Statistics: "The Use of Confidence Limits," by C. R. Stock of the American Cyanamid Co.; "Experimental Design," by C. H. Adams of the Monsanto Chemical Co.; and "The Use of Statistics in Interpreting Specification Limits," by J. Mandel of the National Bureau of Standards.

"Three Years Outdoor Weather Aging of Plastics," by Lucius Gilman of the U. S. Department of the Army.

"Servo Mechanisms in Testing" (with Equipment Demonstration), by B. L. Lewis of the Tinius Olsen Testing Machine Co.

Subcommittee IX on Molds and Molding Processes (J. L. Williams, chairman).—Work on revision of the Tentative Recommended Practice for Transfer Molding of Specimens of Phenolic Materials (D 1046 – 49 T) has shown the need for design of a completely new mold, which is in progress. Present specified mold shrinkage test specimens have been found adequate and development of additional specimens has been discontinued. Revision of the Tentative Recommended Practice for Injection Molding of Test Specimens of Thermoplastic Materials (D 1130 – 50 T) has been initiated. Development of specifications for compression molds for making sheet, from which test specimens can be machined or die cut, is contemplated.

Subcommittee X on Definitions, Nomenclature, and Significance of Tests (C. H. Alexander, chairman).—Definitions for a number of terms have been developed for addition to the Tentative Definitions of Terms Relating to Plastics (D 883 – 53 T). Definitions for additional terms are being developed. Review and revision of Standard Descriptive Nomenclature of Objects Made from Plastics (D 675 – 45) has been initiated.

Subcommittee XIV on Conditioning (A. C. Webber, chairman).—The Standard Method of Conditioning Plastics and Electrical Insulating Materials for Testing (D 618 – 53) is currently being revised in minor details to improve its usefulness and specificity. The Tentative Specifications for Enclosures and

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[3] ASTM BULLETIN, No. 194, December, 1953, p. 67 (TP211).

Servicing Unit for Tests Above and Below Room Temperature (D 1197 - 52 T) have been revised as recommended in this report and further revision is contemplated. Work is continuing on methods of measuring humidity in small enclosures. The work of this subcommittee is a joint activity with Committee D-9 on Electrical Insulating Materials.

This report has been submitted to letter ballot of the committee, which consists of 166 members; 104 members returned their ballots, of whom 90 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

R. K. WITT,
Chairman.

G. M. ARMSTRONG,
Secretary.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee D-20 presented to the Society through the Administrative Committee on Standards revisions of Tentative Methods of Test for Tensile Properties of Thin Plastic Sheets and Films (D 882 - 49 T).

The revision was accepted by the Standards Committee on September 28, 1954, and the revised Methods D 882 appear in the 1954 Supplement to Book of ASTM Standards, Part 6.

APPENDIX

RECOMMENDATIONS AFFECTING STANDARDS ON PLASTICS

In this Appendix are given proposed revisions in certain standards and tentatives on plastics which are referred to earlier in this report. These standards and tentatives appear in their present form in the 1952 Book of ASTM Standards, Part 6, or in its 1953 Supplement, as indicated by the final number in the ASTM designation.

REVISION OF TENTATIVES

Committee D-20, concurring with Committee D-9 on Electrical Insulating Materials, recommends revisions in the following two tentatives:

Tentative Specifications for Phenolic Molding Compounds (D 700 – 52 T):

The committee recommends that this tentative be revised in order to clarify the intended use of the determination of free ammonia for single-stage compounds, to read as follows:

Table I.—Change the last sentence in Footnote (*a*) to read as follows by the addition of the italicized words:

> Single-stage compounds shall have a maximum free ammonia content of 0.02 per cent, when determined *on a molded test specimen* in accordance with the Standard Methods of Test for Ammonia in Phenol-Formaldehyde Molded Materials (ASTM Designation: D 834).

Tentative Specifications for Enclosures and Servicing Units for Tests Above and Below Room Temperature (D 1197 – 52 T):

The committee recommends that this tentative be revised, to permit more practicable design of enclosures and to improve the determination of performance characteristics, to read as follows:

Table I.—Change the requirements for Time Constant max, sec, for Grade A from "50" to "200," and for Grade B from "75" to "275."

Section 8(a), Temperature Fluctuation.—After third sentence, insert the following:

"A recording instrument of equal deflection sensitivity may also be employed."

In the fourth sentence, change "10 min" to "15 min."

Section 8(b), Temperature Differential.—Change the second sentence to read as follows:

> One junction shall be positioned within 2 in. of the locations of the specimen to be tested, and the second placed successively at the approximate center of each cubic foot of available work space (except that for chambers containing less than 4 cu ft, the second junction shall be placed at the center of each 6-in. cube).

Section 8(e), Temperature Drift.—Change the first sentence to read as follows:

> Temperature drift shall be determined by means of the "standard specimen" or of an instrument of equal or greater thermal inertia, except that a device of lower thermal inertia may be used provided that the temperature is taken as being the mean of the highest and lowest temperatures observed over a 15 min period.

Change the last sentence to read as follows:

> The temperature drift shall be the maximum deviation of any subsequent reading (or mean reading) from the original 2-hr reading.

The committee recommends revisions in the following five tentatives:

Tentative Method of Test for Impact Resistance of Plastics and Electrical Insulating Materials (D 256 - 47 T):

The committee recommends that this method be revised as appended hereto,[1] in order to include a statement of significance and an additional procedure applicable to certain plastics materials having Izod impact strengths below 0.5 ft-lb.

Tentative Specifications for Molds for Test Specimens of Plastic Molding Materials (D 647 - 51 T):

Contingent upon the withdrawal of the Tentative Recommended Practice for Transfer Molding of Specimens of Phenolic Materials (D 1046 - 47 T), as recommended in this report, delete the requirements for the mold employed in that recommended practice, as follows:

Section 6.—Delete and renumber subsequent sections accordingly.

Figure 6.—Delete and renumber subsequent figures accordingly.

Section 4(b).—Change reference to "Fig. 8" to read "Fig. 7."

Section 7.—Change reference to "Fig. 7" to read "Fig. 6."

Tentative Method of Test for Brittleness Temperature of Plastics and Elastomers by Impact (D 746 - 52 T):

The committee recommends that this tentative be revised, to include a simplified provisional procedure for acceptance testing, as follows:

Section 1.—Add a new sentence to read as follows: "Two routine inspection and acceptance procedures are also provided."

Section 7(g).—Change the heading "*Routine Inspection*" to read "*Routine Inspection and Acceptance*"; also designate this procedure as "Method A," and add a new Method B to read as follows:

> *Method B.*—This procedure is particularly applicable to materials having a spread of 5 C or less, between complete failure and complete non-failure. In such a case, it shall be satisfactory to accept materials on a basis of testing a minimum of five specimens at a specified temperature, as stated in the relevant material specifications. None shall fail.

Section 9.—Designate as Paragraph 9 (*a*) and add Paragraph (*b*) to read as follows:

> (*b*) For routine inspection and acceptance testing only, the following shall be reported in lieu of (*1*), (*2*), and (*3*) of Paragraph (*a*):
> (*1*) Number of specimens tested,
> (*2*) Temperature of test, and
> (*3*) Number of failures.

Tentative Method of Test for Resistance to Abrasion (Optical Effects) of Transparent Plastics (D 1044 - 49 T):

The committee recommends that this method be revised as appended hereto,[1] to improve the precision of the method.

Tentative Definitions of Terms Relating to Plastics (D 883 - 53 T):

The committee recommends that these tentative definitions be revised by the addition of the following:

> *Bag Molding.*—A method of molding or laminating which involves the application of fluid pressure, usually by means of air, steam, water or vacuum, to a flexible material which transmits the pressure to the material being molded or bonded.
>
> *Blocking, n.*—An adhesion between touching layers of plastic such as that which may develop under pressure during storage or use.
>
> *Cold Flow.*—See Creep.
>
> *Creep, n.*—The time-dependent part of the strain which results from the application of a constant stress to a solid at a constant temperature. (Also referred to as Cold Flow.)
>
> *Delamination, n.*—The separation of the layers of material in a laminate.

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[1] The revision was accepted by the Society, and the method as revised appears in the 1954 Supplement to Book of ASTM Standards, Part 6.

Nonrigid Plastic.—A plastic which has a stiffness or apparent modulus of elasticity of not over 10,000 psi at 23 C when determined in accordance with the Standard Method of Test for Stiffness in Flexure of Plastics (ASTM Designation: D 747).

Rigid Plastic.—A plastic which has a stiffness or apparent modulus of elasticity greater than 100,000 psi at 23 C when determined in accordance with Method D 747.

Semirigid Plastic.—A plastic which has a stiffness or apparent modulus of elasticity of between 10,000 and 100,000 psi at 23 C when determined in accordance with Method D 747.

REVISION OF STANDARDS AND REVERSION TO TENTATIVE

The committee recommends that the following two standards be revised and reverted to tentative:

Standard Method of Test for Measuring the Molding Index of Thermosetting Molding Powder (D 731 – 50):

The committee recommends that this method be revised as appended hereto,[1] to improve its utility for hard flow materials. This method will be revised later to include an improved procedure for soft flow materials.

Standard Descriptive Nomenclature of Objects Made from Plastics (D 675 – 45):

The committee recommends that this method be revised to clarify the descriptions of recommended terms and to bring them into agreement with the present usage, as follows:

Title.—Change to read: "Nomenclature of Descriptive Terms Pertaining to Plastics."

Section 1(a).—In the first sentence, delete "which can be seen but."

Section 1(b).—Under Recommended Nomenclature change the following six terms to read as follows:

Bubble.—Internal void or a trapped globule of air or other gas.

Chalking.—Dry, chalk-like appearance or deposit on the surface of a plastic. (See also *Frosting, Surface-Haze, Lubricant-Bloom.*)

Crazing.—Fine cracks at or under the surface of a plastic.

Dull Surface.—Delete this term and the definition.

Fish-Eye.—Small globular mass which has not blended completely into the surrounding material and is particularly evident in a transparent or translucent material.

Heat Mark.—Extremely shallow depression or groove in the surface of a plastic having practically no depth (its area being very large compared with its depth) and visible because of a sharply defined rim or a roughened surface. (See also *Sink Mark.*)

ADOPTION OF TENTATIVES AS STANDARD

The committee recommends that the following six tentatives be approved for reference to letter ballot of the Society for adoption as standard without revision:

Tentative Specifications for:

Primary Octyl Phthalate Ester Plasticizers (D 1249 – 52 T).

Tentative Methods of Test for:

Compressive Properties of Rigid Plastics (D 695 – 52 T),
Bearing Strength of Plastics (D 953 – 48 T),
Apparent Density and Bulk Factor of Granular Thermoplastic Molding Powder (D 1182 – 51 T),
Measurement of Changes in Linear Dimensions of Nonrigid Thermoplastic Sheeting or Film (D 1204 – 52 T), and
Specific Viscosity of Vinyl Chloride Polymers (D 1243 – 52 T).

ADOPTION AS STANDARD OF TENTATIVE REVISIONS OF STANDARDS

The committee recommends that the tentative revisions[2] of the following two standards be approved for reference to letter ballot of the Society for adoption as standard without revision:

Tentative Revision of Standard Methods of Test for:

Diffusion of Light by Plastics (D 636 – 43), and
Luminous Reflectance, Transmittance, and Color of Materials (D 791 – 50).

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[2] 1953 Supplement to Book of ASTM Standards, Part 6.

REVISION OF STANDARD, IMMEDIATE ADOPTION

Committee D-20, concurring with Committee D-9 on Electrical Insulating Materials, recommends for immediate adoption the revision of the standard as indicated below and requests the nine-tenths affirmative vote at the Annual Meeting in order that this revision may be referred to the Society for letter ballot:

Method of Conditioning Plastics and Electrical Insulating Materials for Testing (D 618 – 53):

The committee recommends that this method be revised to increase the usefullness and specificity of the method to read as follows:

Section 4(b), Procedure B.—Delete the parenthetical phrase "(or other suitable desiccant)."

Note 3.—Add a new sentence to read as follows: "Other enclosures, desiccants, or desiccating techniques may be used which produce and maintain an atmosphere equivalent to that over anhydrous calcium chloride."

Note 5.—Add a new Note 5 following Note 4, renumbering the other notes accordingly:

NOTE 5.—It has been found that, for certain tests and materials, more reliable data are obtained in enclosures with circulating rather than still air. In such cases enclosures with circulating air should be used.

Section 4(f).—Add as a new Note 9 the same note as Note 5 given above.

WITHDRAWAL OF TENTATIVES

The committee recommends that the Tentative Method of Test for Water Vapor Permeability of Plastic Sheets (D 697 – 42 T) be discontinued. This method has been superseded by the Tentative Methods of Test for Measuring Water Vapor Transmission of Materials in Sheet Form (E 96 – 53 T).

The committee recommends the withdrawal of the Tentative Method of Test for Weight Loss of Plastics on Heating (D 948 – 47 T) which has been superseded by the Tentative Specifications for Cell-Type Oven with Controlled Rates of Ventilation (E 95 – 52 T).

The committee also recommends the withdrawal of the Tentative Recommended Practice for Transfer Molding of Specimens of Phenolic Materials (D 1046 – 49 T), since it is no longer used, is not generally satisfactory, and is not in agreement with present techniques of transfer molding.

REPORT OF COMMITTEE D-21

ON

WAX POLISHES AND RELATED MATERIALS*

Committee D-21 on Wax Polishes and Related Materials held one meeting during the year: at Washington, D. C., on February 4 and 5, 1954. In addition, three of the subcommittees met in Cincinnati, Ohio, on May 26, 1954.

Additions and changes during the year brought the total membership of the committee to 54, of whom 23 are classified as producers, 11 as consumers, and 20 as general interest members. There is one consulting member.

The following changes in subcommittee chairmanship occurred during the year: C. S. Kimball replaced F. J. Pollnow, Jr., as chairman of Subcommittee IV on Performance, and Gerald DeNapoli replaced Donald M. King as chairman of Subcommittee III on Chemical and Physical Testing.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, W. W. Walton.
Vice-Chairman, J. V. Steinle.
Secretary, B. S. Johnson.

NEW TENTATIVE

The committee recommends the Method of Test for Paraffin-Type Hydrocarbons in Carnauba Wax for publication as tentative as appended hereto.[1]

This recommendation has been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[2]

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Nomenclature (J. T. Hohnstine, chairman) has prepared several definitions of terms requested by the other subcommittees. They will be included in a glossary of terms which is in preparation.

Subcommittee II on Raw Materials (Melvin Fuld, chairman) developed the chromatographic method for determining paraffinic hydrocarbons which is recommended earlier in this report for publication as tentative. The subcommittee has also published as information in the April, 1954, issue of the ASTM BULLETIN the following methods:

Proposed Method of Test for the Index of Refraction of Carnauba Wax, and
Proposed Method of Test for Concentrating Additives in Waxes.

This group is currently investigating methods for determining melting point, acid number, and saponification number of the natural waxes.

Subcommittee III on Physical and Chemical Testing (Gerald DeNapoli, chairman) is examining methods for determining the viscosity and stability of water emulsion floor waxes. The problem of obtaining a realistic flash point on viscous solvent type waxes is also under investigation. Existing methods produce low values probably because of inadequate agitation of the sample.

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13–18, 1954.

[1] The new tentative was accepted by the Society and appears in the 1954 Supplement to Book of ASTM Standards, Part 4.

[2] The letter ballot vote on this recommendation was favorable; the results of the vote are on record at ASTM Headquarters.

Subcommittee IV on Performance Tests (C. S. Kimball, chairman).—The Section on Slip Resistance has completed its preliminary work on the Sigler and the James type of slip tester, and methods utilizing these machines have been published as information in the February, 1954, issue of the ASTM BULLETIN.

Work is now progressing on the development of a ground glass surface which it is hoped can be used as a secondary standard for the calibration of these machines. The Section on Service Life is investigating methods of testing water spot resistance of floor waxes. A task group has also been set up to study test methods for abrasive wear. The Section on Appearance is completing its work on methods of application for water emulsion floor waxes. Methods for measuring color, gloss, and film transparency are now being studied.

Subcommittee V on Specifications (W. H. Joy, chairman) has prepared a list of specification properties of water emulsion floor wax which includes discussion of the significance of the various properties. This has been circulated to the members of Committee D-21 for comment. The writing of actual specifications still awaits development by the other subcommittees of test methods for the properties involved.

This report has been submitted to letter ballot of the committee, which consists of 54 voting members; 41 members returned their ballots, of whom 36 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

W. W. WALTON,
Chairman.

B. S. JOHNSON,
Secretary.

REPORT OF COMMITTEE D-23

ON

CELLULOSE AND CELLULOSE DERIVATIVES*

Committee D-23 on Cellulose and Cellulose Derivatives, held one meeting during the year: in Chicago, Ill., on September 10, 1953. The Executive Subcommittee met in New York City on February 16, 1954.

The committee is presently composed of 49 members, of whom 14 are classified as producers, 14 as consumers, and 21 as general interest members.

R. M. Levy resigned as chairman of Subcommittee II on Cellulose, and was replaced by O. A. Battista.

The election of officers for the ensuing term of two years will take place at a meeting scheduled for September, 1954, in New York N.Y.

NEW TENTATIVE

The committee recommends that the following method be accepted for publication as tentative as appended hereto:[1]

Tentative Method of Test for:

Viscosity of Cellulose Derivatives by Ball-Drop Method

REVISION OF STANDARD AND REVERSION TO TENTATIVE

The committee recommends that the Standard Methods of Testing Cellulose Acetate (**D 871 – 48**)[2] be revised and reverted to tentative as appended hereto.[3] The revision consists of changes in the sections on Ash, Acidity, Combined Acetic Acid and Acetyl Content, and Viscosity.

The recommendations appearing in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[4]

ACTIVITIES OF SUBCOMMITTEES

Subcommittee II on Cellulose (O. A. Battista, chairman), in collaboration with the Cellulose Division of the American Chemical Society, originally prepared a method for moisture in cellulose which is being completed.[5]

The nine other task groups are studying methods or conducting survey questionnaires at this time. Two methods for extractives are under consideration and a tentative procedure will soon be presented by this task group. The viscosity task group has completed a preliminary draft of the intrinsic viscosity method, and work is now under way on procedures for preparing and standardizing solvent and for standardizing viscometers.

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13–18, 1954.

[1] The new tentative was accepted by the Society and appears in the 1954 Supplement to Book of ASTM Standards, Part 4.

[2] 1952 Book of ASTM Standards, Part 4.

[3] The revision was accepted by the Society and the method as revised appears in the 1954 Supplement to Book of ASTM Standards, Part 4.

[4] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

[5] See Editorial Note, p. 541.

Subcommittee III on Organic Esters (L. B. Genung, chairman) prepared the revision of the Standards Methods of Testing Cellulose Acetate (D 871 - 48) and the new tentative method, Viscosity of Cellulose Derivates by Ball-Drop Method, referred to earlier in the report. The viscosity method was prepared in collaboration with Subcommittee IV.

The next project will be to revise the Method of Test for Acetyl and Butyryl Content of Cellulose Acetate Butyrate (D 817 - 49) in cooperation with Committee D-20. Test methods for moisture, ash, free acidity, and viscosity as described in the Cellulose Acetate Methods D 871 will be used or adapted.

Subcommittee IV on Inorganic Esters (C. B. Gilbert, chairman) has under way experimental work regarding effect of the strength of ethyl acetate used in the solvent mixture for the viscosity determination. This is in connection with a revision of the Standard Specifications and Tests for Soluble Nitrocellulose (D 301 - 50),[5] formerly under the jurisdiction of Committee D-1.

Subcommittee V on Cellulose Ethers (R. S. Apple, chairman) is completing methods for testing methylcellulose.[5]

Considerable progress has been made on selection of a procedure for determining purity of sodium carboxymethyl cellulose (CMC); the work has narrowed down to one method, which is being cross checked by two laboratories before being submitted for evaluation by the other laboratories in the task group. Methods for viscosity are being reviewed.

Subcommittee VI on Statistics (E. J. Delate, chairman) is available for consultation by the other subcommittees to set up design experiments and interpret data. It also plans to prepare material for the purpose of educating and familiarizing the group with statistical tools.

This report has been submitted to letter ballot of the committee, which consists of 49 members; 34 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

F. A. Simmonds,
Chairman.

W. W. Becker,
Secretary.

Editorial Note

Subsequent to the Annual Meeting, Committee D-23 presented to the Society through the Administrative Committee on Standards the following recommendations:

Tentative Methods of:

Testing Methylcellulose (D 1347 - 54 T), and
Test for Moisture in Cellulose (D 1348 - 54 T).

Revision and Reversion to Tentative of:

Standard Specifications and Tests for Soluble Nitrocellulose (D 301 - 50).

These recommendations were accepted by the Standards Committee on November 10, 1954, and the new and revised methods and specifications appear in the 1954 Supplement to Book of ASTM Standards, Part 4.

REPORT OF COMMITTEE E-1

ON

METHODS OF TESTING*

Committee E-1 on Methods of Testing held three meetings during the year: on July 1, 1953, October 22, 1953, and April 6, 1954.

During ASTM Committee Week in Washington, D. C., on February 1 to 5, 1954, meetings were held of fifteen E-1 subcommittees and task groups. Subcommittees 17 on Thermometers, 18 on Hydrometers, 19 on Glassware Laboratory Apparatus, 21 on Metalware Laboratory Apparatus, and 26 on Filtration Materials met at ASTM Headquarters on November 30 and December 1 to 3, 1953. Also Subcommittees 17, 19, and 26 met in Washington, D. C., on May 17 and 18, 1954. Arrangements have been made for meetings of six subcommittees and eight task groups during the 1954 Annual Meeting of the Society.

A new Subcommittee on Microscopy is being organized under the chairmanship of F. G. Foster, of Bell Telephone Labs. Following the Symposium on Light Microscopy,[1] sponsored by Committee E-1 at the 1952 Annual Meeting of the Society, there was considerable interest evinced in this subject which indicated a need for a technical committee to deal with the entire range of microscopy, including both light microscopy and electron microscopy. The personnel of this new subcommittee will include representatives designated by interested ASTM technical committees and adviser members having specialized technical knowledge and experience in this field. A number of microscopic techniques for the examination and evaluation of materials are now covered in various Society standards. Other methods are under study. As new materials become available they may require new microscopic methods and techniques for their examination and evaluation. It is believed that this new E-1 subcommittee can be of assistance in the development and publication of such methods. It will also serve in an advisory capacity to other Society committees.

A task group has been appointed under the chairmanship of Robert Burns to survey the subject of test methods for thermal shock.

Committee E-1 has under way plans for sponsoring four symposiums during the next two years on the following subjects:

Symposium on Effect of Speed of Testing of Non-Metallic Materials, under the auspices of Subcommittee 2 on Effect of Speed in Mechanical Testing,

Symposium on Tension Testing of Non-Metallic Materials, under the auspices of Subcommittee 4 on Tension Testing,

Symposium on Impact Testing, under the auspices of Subcommittee 7 on Impact Testing, and

Symposium on Viscosity, under the auspices of Subcommittee 9 on Rheological Properties.

The election of officers resulted in the re-election of the following for the ensuing term of two years:

Chairman, J. R. Townsend.
Vice-Chairman, R. L. Templin.

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13–18, 1954.

[1] Issued as separate publication *ASTM STP No. 143.*

RECOMMENDATIONS ACCEPTED BY THE ADMINISTRATIVE COMMITTEE ON STANDARDS

Subsequent to the 1953 Annual Meeting, Committee E-1 presented to the Society through the Administrative Committee on Standards the following recommendations:

Tentative Specifications for:

ASTM Hydrometers (E 100 - 53 T), and

Tentative Revision of Standard Specifications for:

ASTM Thermometers (E 1 - 53), consisting of the addition of specifications for two antifreeze freezing point thermometers.

These recommendations were accepted by the Standards Committee on September 9, 1953; the new Tentative Specifications E 100 appear in the 1953 Supplement to Book of ASTM Standards, Parts 3 and 5, and the tentative revision of Standard Specifications E 1 appears in Parts 3, 4, and 5 of the 1953 Supplement.

On February 23, 1954, the Administrative Committee on Standards accepted the following recommendations submitted by Committee E-1:

Tentative Method of Test for:

Saybolt Furol Viscosity of Asphaltic Materials at High Temperatures (E 102 - 54 T), and

Tentative Revision of Standard Specifications for:

ASTM Thermometers (E 1 - 53), consisting of the addition of specifications for five ASTM Saybolt Thermometers.

The new Tentative Method E 102 appears in the 1953 Supplement to Book of ASTM Standards, Part 3, and the tentative revision of Standard Specifications E 1 appears in Parts 3, 4, and 5 of the 1953 Supplement.

PROPOSED SPECIFICATIONS TO BE PUBLISHED AS INFORMATION

The committee recommends that the Proposed Specifications for Apparatus for Determination of Water by Distillation be published as information only as appended hereto.[2] These specifications cover equipment used in the Method of Test for Water in Petroleum Products and Other Bituminous Materials (D 95 - 46).

NEW TENTATIVE

The committee recommends for publication as tentative the Method for Rapid Indentation Hardness Testing of Metallic Materials, as appended hereto.[3]

REVISION OF TENTATIVES

The committee recommends the following revisions of three tentative methods and specifications:

Tentative Methods of Tension Testing of Metallic Materials (**E 8 - 52 T**).[4]—The following revision of these methods provides two tension test bars for testing powdered metals as recommended by Committee B-9 on Metal Powders and Metal Powder Products:

New Section.—Add the following as a new Section 18, renumbering the present sections accordingly:

> 18. *Powdered Metals.*—For testing powdered metals the test specimens shown in Fig. 19 shall be used, unless otherwise provided in the product specifications.

Figure 19.—Add as a new Fig. 19 the two tension test specimens for powdered metals shown in the accompanying Fig. 1, renumbering the present figures accordingly.

Tentative Method of Test for Brinell Hardness of Metallic Materials (**E 10 - 50 T**).[4]—The following revisions include a change in the scope to indicate that the method is applicable for referee tests where higher accuracy is needed than is provided in Brinell test methods used

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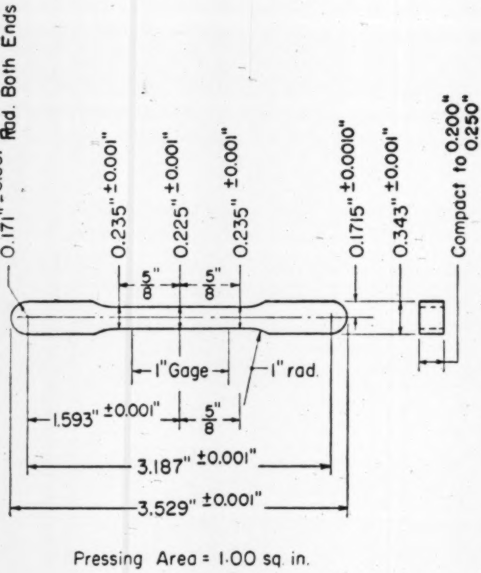
[2] See p. 554.

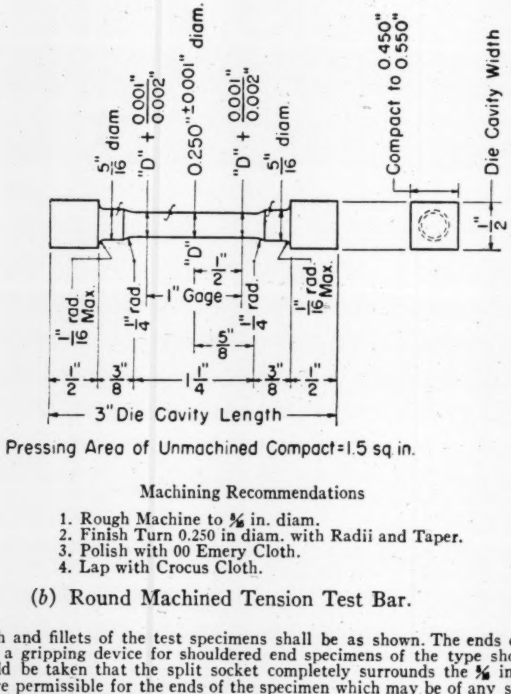
[3] The new tentative was accepted by the Society and appears in the 1954 Supplement to Book of ASTM Standards, Parts 1 and 2.

[4] 1952 Book of ASTM Standards, Parts 1 and 2.


0.171" ±0.001" Rad. Both Ends
0.235" ±0.001"
0.225" ±0.001"
0.235" ±0.001"
0.1715" ±0.0010"
0.343" ±0.001"
Compact to 0.200" 0.250"
5/8"
5/8"
1" Gage
1" rad.
1.593" ±0.001"
5/8"
3.187" ±0.001"
3.529" ±0.001"
Pressing Area = 1.00 sq. in.

Dimensions Specified are Those of the Compact When in the Die.

(*a*) Flat Unmachined Tension Test Bar.


5/16" diam.
"D" + 0.001"/0.002"
0.250" ±0.001" diam.
"D" + 0.001"/0.002"
5/16" diam.
Compact to 0.450" 0.550"
Die Cavity Width
1/2"
"D"
1/2"
1/16" rad. Max.
1/4" rad
1" Gage
1/4" rad.
1/16" rad. Max.
5/8"
1/2"
3/8"
1 1/4"
3/8"
1/2"
3" Die Cavity Length
Pressing Area of Unmachined Compact=1.5 sq. in.

Machining Recommendations

1. Rough Machine to 5/16 in. diam.
2. Finish Turn 0.250 in diam. with Radii and Taper.
3. Polish with 00 Emery Cloth.
4. Lap with Crocus Cloth.

(*b*) Round Machined Tension Test Bar.

NOTE.—The gage length and fillets of the test specimens shall be as shown. The ends of the specimen as shown are designed for use with a gripping device for shouldered end specimens of the type shown in Fig. 2. Using this gripping device care should be taken that the split socket completely surrounds the 5/16 in. diameter section of the specimen. Other designs are permissible for the ends of the specimen which may be of any shape to fit the holders of the testing machine in such a way that the load shall be axial.

FIG. 1.—Standard Tension Test Specimens for Powdered Metals.

primarily for production testing. Appendix I of the method, which contains information on the Brinell type hardness test in which the depth of impression is measured in place of diameter, is to be deleted since it is no longer necessary with the publication of the Method for Rapid Indentation Hardness Testing. The detailed changes are as follows:

Section 1.—Add the following words at the end of this section on scope: "where a high degree of accuracy is required."

Section 2(b).—Change the fifth sentence to read as follows by addition of the italicized words: "*In general*, a standard ball 10 mm. in diameter with applied loads of 3000 kg., 1500 kg., or 500 kg. shall be used."

Also add the phrase "unless otherwise specified" at the end of the last paragraph of Section 2(*b*).

Section 3(a).—Change the third sentence to read as follows by the addition of the italicized words: "The design of the testing machine shall be such that no rocking or lateral movement of the indenter *or specimen* is permitted while the load is being applied."

Section 4.—In Paragraph (*a*), change the reference to Appendix II to read Appendix I; also add the following sentence: "The minimum width must conform with the requirements of Section 5 (*d*)."

Transfer Paragraph (*c*) to appear as Section 5 (*f*); also transfer Paragraph (*d*) to appear as Section 5 (*b*), relettering the other paragraphs in Section 5 accordingly.

Section 5(d).—Change this section to read as follows: "(*d*) The distance of the center of the indentation from the edge of the specimen or edge of another indentation shall be at least two and one-half times the diameter of the indentation."

Section 7.—Add the following as a new Paragraph (*a*), also rearrange and reletter the present paragraphs as indicated below:

> 7. (*a*) There are two acceptable methods of calibrating Brinell machines:
>
> (*1*) Separate verification of load application and impression measurement, and
>
> (*2*) The comparison specimen method described in Section 7 (*e*), (*f*), and (*g*).

Reletter Paragraph (*a*) as (*b*), change (*b*) to (*e*), (*c*) to (*g*), (*d*) to (*f*), (*e*) to (*c*), and (*f*) to (*d*).

Appendix I.—Omit this Appendix.

Tentative Specifications for ASTM Hydrometers (**E 100 - 53 T**).[5]—The requirements for specific gravity hydrometers for light liquids and for heavy liquids as shown in the accompanying Table I are recommended for inclusion in Table I of Specifications E 100.

REVISION OF STANDARD AND REVERSION TO TENTATIVE

The committee recommends that the Standard Definitions of Terms Relating to Methods of Testing (**E 6 - 36**)[4] be revised and reverted to tentative as appended hereto.[6] These revised definitions were prepared following a thorough study of current nomenclature and definitions of the principal terms used in methods of mechanical testing. The revised definitions are based primarily on practices pertaining to the testing of structural materials. They will be expanded to cover other materials as rapidly as agreement can be reached on suitable revisions or definitions. These definitions are being published in order to encourage uniformity of terminology in product specifications.

REVISION OF STANDARDS, IMMEDIATE ADOPTION

The committee recommends for immediate adoption the following revisions of two standards and accordingly requests the necessary nine-tenths affirmative vote at the Annual Meeting in order that these recommendations may be referred to letter ballot of the Society:

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[5] 1953 Supplement to Book of ASTM Standards, Parts 3 and 5.

[6] The revised definitions were accepted by the Society and appear in the 1954 Supplement to Book of ASTM Standards, Parts 1, 2, 3, 4, 6, and 7.

Standard Specifications for ASTM Thermometers (**E 1 – 53**).[5]—Revise this standard as follows:

Section 6(a).—Change the third sentence to read as follows by the omission of words in brackets: "On Partial Immersion Thermometers, an immersion line [of approximately the same length as the longest graduation line] shall be etched on the front of the thermometer at the distance above the bottom of the bulb as specified in Table I within a tolerance of ±0.5 mm."

Table I.—Change the various thermometer specifications in this table as follows:

Revise the ASTM Open Flash Thermometer 11 C to require graduations numbered at each multiple of 20 C rather than at every 10 C.

Revise Kinematic Viscosity Thermometers 28F to 30F, 44F to 48F, and 72F to 74F, inclusive, to change the bulb diameter from "not less than 6.0 mm. and not greater than stem" to read "6.0 to 7.0 mm"; also change the stem diameter from "6.5 to 7.5 mm." to read "6.5 to 8.0."

Table II.—Add the following average stem temperatures for Engler Viscosity Thermometers 23C to 25C, as furnished

TABLE I.—SPECIFICATIONS FOR ASTM HYDROMETERS.

Specific Gravity Hydrometers				**Specific Gravity Hydrometers**	
Light Liquids				Heavy Liquids	
Designation	Nominal Specific Gravity Range, deg	Designation	Nominal Specific Gravity Range, deg	Designation	Nominal Specific Gravity Range, deg
82H.......	0.645 to 0.705	98H......	0.945 to 1.005	111H....	1.000 to 1.055
83H.......	0.695 to 0.755			112H....	1.045 to 1.105
84H.......	0.745 to 0.805			113H....	1.095 to 1.555
85H.......	0.795 to 0.855			114H....	1.145 to 1.205
86H.......	0.845 to 0.905			115H....	1.195 to 1.255
87H.......	0.895 to 0.955			116H....	1.245 to 1.305
88H.......	0.945 to 1.005			117H....	1.295 to 1.355
89H.......	0.995 to 1.055			118H....	1.345 to 1.405
90H.......	1.045 to 1.105			119H....	1.395 to 1.455
				120H....	1.445 to 1.505

Liquids for which Hydrometers are Intended	Petroleum Products and Other Liquids of Similar Surface Tensions (33 dynes per cm or less)	Alcohols[a]	General Use
Standard Temperature......	60/60F	60/60F	60/60F
Subdivisions...............	0.0005	0.0005	0.0005
Intermediate Lines at......	0.001	0.001	0.001
Main (numbered) Lines at.	0.005	0.005	0.005
Scale Error at any Point not to Exceed..........	0.0005	0.0005	0.0005
Total Length.............	300 to 335 mm	300 to 335 mm	300 to 335 mm
Length of Scale...........	125 to 145 mm	125 to 145 mm	125 to 145 mm
Body Diameter...........	18 to 25 mm	18 to 25 mm	18 to 25 mm
Stem Diameter...........	4.0 mm, min	4.0 mm, min	4.0 mm, min

[a] For specific gravities less than 0.950, alcoholic solutions may be tested with hydrometers 84H to 87H.

by the National Bureau of Standards:

Standardization Temperature	Average Temperature of Emergent Mercury Column
18 TO 28 C. THERMOMETER 23 C.	
20 C.	22 C.
25 C.	25 C.
39 TO 54 C. THERMOMETER 24 C.	
40 C.	35 C.
45 C.	36 C.
95 TO 105 C. THERMOMETER 25 C.	
95 C.	75 C.
100 C.	64 C.

Standard Methods of Test for Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials (**E 18 - 42**).[4]—The revisions in these methods comprise changes in the requirements for major load application and the inclusion of an Appendix consisting of two tables containing data for corrections for Rockwell Diamond Penetrator Hardness Test on Cylindrical Specimens. The changes are as follows:

Section 4(f).—Change the description of the major load application for the Rockwell hardness test to read as follows:

TABLE II.—CORRECTIONS TO BE ADDED TO ROCKWELL C, A, AND D VALUES OBTAINED ON CYLINDRICAL SPECIMENS OF VARIOUS DIAMETERS.

Dial Reading	¼ in.	⅜ in.	½ in.	⅝ in.	¾ in.	⅞ in.	1 in.	1¼ in.	1½ in.
20	6.0	4.5	3.5	2.5	2.0	1.5	1.5	1.0	1.0
25	5.5	4.0	3.0	2.5	2.0	1.5	1.0	1.0	1.0
30	5.0	3.5	2.5	2.0	1.5	1.5	1.0	1.0	0.5
35	4.0	3.0	2.0	1.5	1.5	1.0	1.0	0.5	0.5
40	3.5	2.5	2.0	1.5	1.0	1.0	1.0	0.5	0.5
45	3.0	2.0	1.5	1.0	1.0	1.0	0.5	0.5	0.5
50	2.5	2.0	1.5	1.0	1.0	0.5	0.5	0.5	0.5
55	2.0	1.5	1.0	1.0	0.5	0.5	0.5	0.5	0
60	1.5	1.0	1.0	0.5	0.5	0.5	0.5	0	0
65	1.5	1.0	1.0	0.5	0.5	0.5	0.5	0	0
70	1.0	1.0	0.5	0.5	0.5	0.5	0.5	0	0
75	1.0	0.5	0.5	0.5	0.5	0.5	0	0	0
80	0.5	0.5	0.5	0.5	0.5	0	0	0	0
85	0.5	0.5	0.5	0	0	0	0	0	0
90	0.5	0	0	0	0	0	0	0	0

TABLE III.—CORRECTIONS TO BE ADDED TO ROCKWELL 15 N, 30 N, AND 45 N VALUES OBTAINED ON CYLINDRICAL SPECIMENS OF VARIOUS DIAMETERS.

Dial Reading	⅛ in.	¼ in.	⅜ in.	½ in.	¾ in.	1 in.
20	6.0	3.0	2.0	1.5	1.5	1.5
25	5.5	3.0	2.0	1.5	1.5	1.0
30	5.5	3.0	2.0	1.5	1.0	1.0
35	5.0	2.5	2.0	1.5	1.0	1.0
40	4.5	2.5	1.5	1.5	1.0	1.0
45	4.0	2.0	1.5	1.0	1.0	1.0
50	3.5	2.0	1.5	1.0	1.0	0.5
55	3.5	2.0	1.5	1.0	0.5	0.5
60	3.0	1.5	1.0	1.0	0.5	0.5
65	2.5	1.5	1.0	0.5	0.5	0.5
70	2.0	1.0	1.0	0.5	0.5	0.5
75	1.5	1.0	0.5	0.5	0.5	0
80	1.0	0.5	0.5	0.5	0	0
85	0.5	0.5	0.5	0.5	0	0
90	0	0	0	0	0	0

(*f*) Apply the major load by tripping the operating lever without shock. Remove the major load by bringing the operating lever back to its latched position within 2 sec after its motion has stopped. Alternate methods of applying the major load may be used as follows:

(*1*) In the case of materials which do not exhibit plastic flow after application of the major load, the pointer will come to rest before the motion of the operating lever stops, and in this case the operating lever may be brought back to its latched position immediately after the pointer stops to reduce possible errors due to externally caused vibration.

(*2*) In the case of materials which exhibit plastic flow after application of the major load, the pointer will continue to move after the operating lever stops, and in this case the operating lever may be brought back to its latched position at a specified elapsed time between tripping and removal of load (Note). In this case the specified elapsed time shall be recorded with the Rockwell number.

NOTE.—The specified time should be stated in the product specifications.

Section 7(g).—Omit this paragraph which reads as follows:

(*g*) The time of application of the major load shall be established and accurately adhered to when comparing results. As a general rule, an interval of full application of the major load of not more than 1 sec. is best. For soft metals the penetration will "creep," causing variations as high as ten hardness numbers. With such metals the operating lever should be brought back the moment it is seen that the major load is fully applied.

Section 10(f).—Change the description of the major load application for the Rockwell superficial hardness test to read the same as given for Section 4 (*f*) above.

Appendix.—Include in an Appendix the accompanying Tables II and III.

TENTATIVES CONTINUED AS TENTATIVE

The committee recommends that the remaining tentatives under its jurisdiction be continued in their present status as consideration is now being given to further revisions.

The recommendations appearing in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[7]

ACTIVITIES OF SUBCOMMITTEES AND TASK GROUPS

Subcommittee 1 on Calibration of Mechanical Testing Machines and Apparatus (B. L. Wilson, chairman).—Revisions of the Tentative Methods of Verification of Testing Machines (E 4 - 50 T), Verification of Calibration Devices for Verifying Testing Machines (E 74 - 50 T), and Verification and Classification of Extensometers (E 83 - 52 T) are being completed. One of the changes covers the use of balances for the calibration of hardness testing machines to be added to Methods E 4 and E 74.

Subcommittee 2 on Effect of Speed in Mechanical Testing (P. G. McVetty, chairman).—Plans are being completed for the Symposium on Effect of Speed of Testing of Non-Metallic Materials to be held at the 1955 Annual Meeting of the Society. Arrangements for the symposium are being made by a committee under the chairmanship of F. G. Tatnall. This symposium will bring up to date information relating to speed effects on the testing of a wide variety of materials that has been obtained since the previous symposium on this subject sponsored by Committee E-1 in 1948.[8]

Subcommittee 3 on Elastic Strength of Materials (F. M. Howell, chairman):

Task Group on Elastic Constants (Walter Ramberg, chairman) prepared the first draft of a proposed tentative method for determination of Young's modulus at room temperature. This draft is now being revised, based on comments received from the committee at a meeting held in Washington in February.

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[7] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

[8] Symposium on Speed of Testing, *Proceedings*, Am. Soc. Testing Mats., Vol. 48, p. 1129 (1948).

Task Group on Correlation of Definitions Relating to Methods of Testing (P. G. McVetty, chairman) completed a very extensive study of the Standard Definitions of Terms Relating to Methods of Mechanical Testing (E 6 – 36). The revised definitions appended hereto[6] are accordingly recommended for publication as tentative to replace those of the present Standard E 6 – 36.

Subcommittee 4 on Tension Testing (R. L. Templin, chairman).—Under the auspices of this subcommittee, a Symposium on Tension Testing of Non-Metallic Materials is being developed for the 1956 ASTM Annual Meeting, the arrangements for which are being made by a committee under the chairmanship of A. C. Webber. This symposium will comprise about ten papers covering current techniques and practices now being followed in industry in the tension testing of non-metals and should serve as a basis for the development of general methods for determining the tensile properties of such materials.

Revisions in the Tentative Methods of Tension Testing of Metallic Materials (E 8 – 52 T) presented earlier in this report were prepared in cooperation with Committee B-9 on Metal Powders and Metal Powder Products. The scope of the task group under the chairmanship of H. L. Fry, appointed to consider the definitions in Methods E 8 and their relationship to the corresponding definitions in E 6, has been expanded to include the review of the tension test methods in the Tentative Methods and Definitions for the Mechanical Testing of Steel Products (A 370 – 53 T).

The Task Group on Bursting Test (R. L. Heyer, chairman) has submitted a final report which indicates that methods have been found for making other tests, such as a tension test with measurement of elastic properties, on the very thin sheet metals for which the bursting test had been considered. The task group accordingly believes that due to lessening interest in the bursting test for these materials no further work should be undertaken.

Subcommittee 6 on Indentation Hardness (R. H. Heyer, chairman).—The new proposed Tentative Method of Rapid Indentation Hardness Testing of Metallic Materials[3] was prepared by this subcommittee. The revisions of the Brinell Hardness Test Method E 10 and the Rockwell Hardness Test Method E 18 were recommended by this subcommittee.

Revision of the Tentative Method for Diamond Pyramid Hardness of Metallic Materials (E 92 – 52 T) to change the time of loading from "at least 15 sec." to "a specified period of time" is under consideration.

A task group has in preparation a new method of test for portable indentation hardness testers which will include types of testers that use standard loads and indentors.

Subcommittee 7 on Impact Testing (W. W. Werring, chairman).—This subcommittee still has under consideration revisions in the Tentative Methods of Impact Testing of Metallic Materials (E 23 – 47 T).

A Symposium on Impact Testing is planned for the 1955 Annual Meeting of the Society, arrangements for which are being made by a special committee under the chairmanship of F. G. Tatnall. It is expected that the symposium will comprise about ten papers, about one half of which will deal with the effect and evaluation of full scale impact testing of structures, while the others will cover various types of impact tests, including correlation with full-scale testing and a general discussion of the philosophy of impact testing.

Subcommittee 8 on Flexure Testing (H. F. Clemmer, chairman).—This committee has prepared a further draft of a proposed Standard Method for Making Three-Edge Bearing Test of Pipe which is now under study. The method covers procedures for tests of circular pipe and drain pipe of concrete or clay, and cast-iron culvert pipe.

This subcommittee reviewed a proposed Method of Test for Determination of Modulus of Rupture of Fired Dry Pressed Whiteware Specimens at Normal Temperature, prepared by Committee C-21 on Ceramic Whiteware. A number of comments and suggestions were submitted for consideration by Committee C-21.

Subcommittee 9 on Rheological Properties (W. F. Fair, Jr., chairman).—An American Group to handle the secretariat of Technical Committee 66 on Viscosity of the International Standards Organization held an organization meeting on February 3 in Washington. The personnel of this group is identical with that of the E-1 Task Group on Methods and Apparatus for Absolute Viscosity Measurements. A program of work for this ISO committee was formulated. Copies of the Report on Principles Involved in the Determination of Absolute Viscosity prepared by this task group will be sent to members of the ISO committee. Other matters to be submitted for consideration are the new value for the viscosity of water and information on the viscosity oil standards of the American Petroleum Institute and the National Bureau of Standards.

A Symposium on Viscosity is being planned for the 1956 Annual Meeting. Arrangements for the symposium are being made by a special committee under the chairmanship of W. H. Markwood, Jr. This symposium will be sponsored jointly with the Society of Rheology and will comprise about ten technical papers.

The Task Group on Softening Point, under the chairmanship of W. A. Kirklin, which comprises representatives from eight ASTM technical committees, is still endeavoring to reconcile the differences between the Ring-and-Ball Softening Point Methods D 36 – 26 and E 28 – 51 T. Recommendations from Subcommittee 21 covering improvements in the drawings of the metalware apparatus used in Method E 28 are being considered for incorporation in the method.

The Task Group on Saybolt Furol Viscosity of Asphaltic Materials at High Temperatures, under the chairmanship of R. R. Thurston, is giving consideration to several criticisms of Methods E 102.

Subcommittee 10 on Sieves.—L. V. Judson, of the National Bureau of Standards, was appointed as chairman of this subcommittee following the death of the former chairman, A. A. Klein.

A proposed Method of Test for Wet Sieve Analysis of Whiteware Clays, prepared by Committee C-21, was reviewed and a number of comments and suggestions were submitted for consideration.

Subcommittee 11 on Subsieve Testing (L. T. Work, chairman).—The principal activity of this subcommittee has been carried on by the Task Group on Subsieve Testing by the Optical Microscope under the chairmanship of R. P. Loveland. This task group is considering revisions of the Tentative Recommended Practice for Analysis by Microscopical Methods for Particle Size Distribution of Particulate Substances of Subsieve Sizes (E 20 – 51 T) involving the following three subjects: (1) preparation of samples, (2) the count method (usually dark field) for examination of particle size, and (3) the expression of particle size. This group is also cooperating with a task group of Committee D-1 on Paint Materials in preparation of a proposed Recommended Practice for Expression of Particle Size considered primarily from the standpoint of pigments.

Subcommittee 12 on Methods for Density.—C. T. Collett, of the National Bureau of Standards, has been appointed chairman of this subcommittee following resignation of Wilmer Souder, resulting from his retirement. Mr. Collett has been closely associated with Dr. Souder whose experience, energy, and knowledge of this field had been of great value to the subcommittee. Review of the various ASTM methods of test for density is being continued by the task group under J. J. Moran, chairman.

A proposed Method of Test for True Specific Gravity of Fired Whiteware Materials, prepared by Committee C-21, was reviewed and a number of comments and suggestions submitted for consideration.

Subcommittee 15 on Correlation of Chemical Analyses (J. W. Stillman, chairman).—The final draft of Proposed Recommendations on Form of ASTM Methods for Chemical Analysis is now out to letter ballot vote of the subcommittee.

Subcommittee 16 on Thickness Measurement.—Sanford B. Newman of the National Bureau of Standards has been appointed chairman of this subcommittee. The present program of work is being handled by two task groups as follows: (1) on Dimensional Measurements of Electronic Tube Components (C. W. Harman, chairman) and (2) on Calibration of Spindle Pressure of Machinists Micrometer (E. G. Ham, chairman).

Subcommittee 17 on Thermometers (R. M. Wilhelm, chairman).—Further revisions of the Specifications for Thermometers E 1 will be submitted to the Society during the summer based on actions taken by the subcommittee at its meeting in Washington on May 17. Requests received from several technical committees for thermometer specifications not presently available are under study. These include a thermometer for weathering test of butadiene, and a thermometer for the flash point test of vegetable oils with the Pensky-Martens Tester. A set of thermometers for solidification points of various organic chemicals such as benzol, naphthalene, and phenol has been requested by Committee D-16. Standardization of thermometers now used in engine test methods for rating fuels has been requested by Committee D-2.

In 1947 an effort was made to develop more complete specifications than those appearing in the Standard Method of Test for Distillation of Industrial Aromatic Hydrocarbons (D 850 – 50) for the so-called "Barrett" distillation thermometers, but since it was thought that these thermometers would become obsolete and would be replaced by the ASTM Solvents Distillation Thermometers the subject was tabled. It now appears that the "Barrett" thermometers are still being used; the question of specification, therefore, has been reopened and a task group assigned to prepare specifications.

Another subject which has been under consideration for several years is the coordination of the thermometer specifications published by the ASTM and the Institute of Petroleum (London). Some progress has been made by the task group in bringing about a better understanding of the difficulties which must be surmounted before any changes will be accepted by either of the national organizations to bring one into agreement with the other.

A study is to be made of thermometric glasses by a special task group.

Subcommittee 18 on Hydrometers (R. D. Thompson, chairman).—In response to a request from Committee D-2 on Petroleum Products and Lubricants, specifications were prepared for a series of specific gravity hydrometers as counterparts of the API gravity series 1H to 10H. It is anticipated that these instruments will find their principal use on petroleum products destined for export or for use in foreign countries. Specifications have also been prepared for a hydrometer for alcohol testing and for a series of specific gravity instruments for heavy liquids which will be used for various purposes, the most noteworthy being the testing of engine antifreezes. These requirements for hydrometers are being recommended for inclusion in the Tentative Specifications for ASTM Hydrometers (E 100 - 53 T).

The major project ahead of the subcommittee is the preparation of methods of testing hydrometers, and with completion of the specifications it is to be anticipated that significant progress will be made during the coming year.

Subcommittee 19 on Glassware Laboratory Apparatus (J. J. Moran, chairman). —In response to a request from Committee D-2, Subcommittees 19 and 21 cooperated in the preparation of Proposed Specifications for Engler Distillation Equipment (to be used in Method D 86) and for Apparatus for Determination of Water Content of Bituminous Materials[9] (to be used in Method D 95). Both specifications have been approved by Subcommittee 19 and have been submitted to Committee D-2 for further consideration. When the final drafts have been agreed upon, they will first be offered for publication as tentative.

At the request of Committee D-2, a subgroup is preparing specifications for the burets used to measure reference fuels used in knock testing procedures.

Subcommittees 19 and 21 are cooperating also in the preparation of general requirements for drawings of metalware and glassware apparatus.

Subcommittee 21 on Metalware Laboratory Apparatus (E. L. Ruh, chairman).—Agreement was reached on details for drawings covering the softening point apparatus to be used in Method E 28 - 51 T.

The draft prepared by Committee E-3 on Chemical Analyses of Metals on Performance Specifications for Analytical Balances was reviewed and will be studied further during the year.

The Task Group on Laboratory Ovens, under the chairmanship of R. D. Stiehler, is preparing performance requirements for circulating air ovens.

A new *Task Group on Safety Requirements for Using Oxygen and Peroxide Bombs* has been appointed under the chairmanship of M. R. Hoppe. The first meeting of this group will be held in Chicago at the Annual Meeting.

Subcommittee 22 on Hydrogen Ion Determination (E. B. Ashcraft, chairman).—The second draft of a proposed Tentative Method for the Colorimetric Determination of the pH of Aqueous Solutions is under study.

Subcommittee 24 on Cupping Tests (E. F. Lundeen, chairman).—The entire problem of cupping tests was reviewed at length at a meeting of a subgroup held in Pittsburgh in November, 1953. In order to determine the extent of interest in cupping tests, a questionnaire has been prepared and circulated to interested individuals and companies in the ferrous and non-ferrous metals fields to determine the following: (1) the interest in the test, (2) if the interest is for control purposes, and (3) if there is any interest in the use of this test for specification purposes. The replies received to these questions will serve as a basis for a program of work for the subcommittee.

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[9] See p. 554.

Subcommittee 26 on Filtration Materials (T. L. King, chairman).—Substantial agreement has been reached on the content of Proposed Tentative Specifications and Test Methods for Porous Filtering Bodies, and a final draft is under study.

Subcommittee 27 on Low-Temperature Testing of Elastomers and Plastics (R. S. Havenhill, chairman):

Section on Correlation of Test Methods (F. M. Gavan, chairman) held three meetings during the past year. A condensed report of the results of the round-robin low-temperature stiffness tests has been prepared by F. S. Conant.[10] This report compares the performance of various low-temperature stiffness instruments for modulus measurement, such as Scott, Instron, Tate-Emery, Olsen, Simple Beam, Compression, Navy (Corrected), Gehman, Clash-Berg, and Taber. The report also illustrates how the property of modulus changes for various rubber and plastic compounds over a range of temperatures from room temperature to −80 F.

B. G. Labbe has prepared and submitted for ASTM BULLETIN publication a summary of the results of the hardness testing round-robin.[11] This report compares the performance of various low-temperature hardness instruments, such as Shore, Rex, ASTM, P&J, and the Materials Lab Indentometer. The report also illustrates how the property of hardness changes for various rubber and plastic compounds over a range of temperatures from room temperature to −80 F.

A. C. Webber has prepared a report and made recommendations for the future round-robin on brittleness tests.

C. K. Chatten and W. E. Scoville are preparing and analyzing the various methods for obtaining rheological properties of rubber and plastics at low temperatures.

When this work is fully completed, definite recommendations will be made as to the tests that are best suited for the determination of low-temperature behavior of rubber and plastics.

Task Group F on Bend Testing (W. H. Mayo, chairman).—At the organization meeting of this new task group, the chairman presented an extensive review of the various types of bend tests now specified in ASTM standards. This summary showed that there are 151 bend tests now specified of which 137 are for testing metals while 14 are for non-metallic materials.

The committee decided to undertake work on: (1) correlation of bend tests now published and consideration of possible further improvement and standardization, (2) investigation of present bend test methods for possible new applications, and (3) development of new bend test methods where needed. In connection with this program, the subcommittee decided to proceed immediately with the preparation of a set of definitions covering the various types of bend tests now in use, such as the free bend, controlled bend, guided bend, bending around a pin, etc.

This report has been submitted to letter ballot of the committee, which consists of 39 voting members; 39 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

J. R. TOWNSEND,
Chairman.

P. J. SMITH,
Secretary.

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[10] F. S. Conant, "A Study of Stiffness Testing of Elastomers at Low Temperatures," ASTM BULLETIN, No. 199, July, 1954, p. 67 (TP145).

[11] B. G. Labbe, "A Study of Hardness Testing of Elastomers at Low Temperatures," *ibid.*, p. 73 (TP151).

APPENDIX

PROPOSED SPECIFICATIONS FOR APPARATUS FOR DETERMINATION OF WATER BY DISTILLATION[1, 2]

These are proposed specifications and are published as information only. Comments are solicited and should be addressed to the American Society for Testing Materials, 1916 Race St., Philadelphia 3, Pa.

Scope

1. These specifications cover equipment used in Standard Method of Test for Water in Petroleum Products and other Bituminous Materials (ASTM Designation: D 95).[3]

Apparatus Assembly

2. (*a*) Typical assemblies[4] of the apparatus are shown in Figs. 1 and 2. The glass flask has been generally used for petroleum products and the metal still for road materials and tars.

(*b*) Figure 1 shows a Liebig condenser; Fig. 2 a West-type condenser. Either type may be used in any assembly.

Glass Flask

3. The *glass flask* shall have a nominal capacity of 500 ml, be made of heat-resistant glass, and conform to the dimensional requirements and tolerances specified in Fig. 3.

Metal Still

4. The metal still shall have an approximate capacity of 1000 ml. It may be constructed of any suitable metal; but copper is recommended for the vessel, and copper or brass for the lid. Figure 4 shows the essential dimensions and a satisfactory construction of the vessel head and clamp. Other means of closure may be used which provide a tight seal of head to body.

Heater

5. Any suitable gas burner or electric heater may be used with the glass still. With the metal still, a ring gas burner 4 in. in inside diameter and having burner ports on its inner periphery should be used.

Condenser

6. The condenser shall be a Liebig or West straight type with a jacket not less than 400 mm long. Figure 5 shows the general construction of suitable condensers.

Traps

7. The traps shall be of 10 and 25 ml capacities as shown in Figs. 6 and 7, with the following subdivisions and scale error tolerances:

Size of Trap, ml	Range, ml	Smallest Scale Division, ml	Maximum Scale Error, ml
10	0 to 1.0	0.1	0.05
	Over 1.0 to 10.0	0.2	0.1
25	0 to 1.0	0.1	0.05
	Over 1.0 to 25.0	0.2	0.1

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[1] These proposed specifications are under the jurisdiction of ASTM Committee E-1 on Methods of Testing.

[2] Published as information, June, 1954.

[3] 1952 Book of ASTM Standards, Part 5.

[4] Specifications for all glass apparatus with ball-and-socket joints are also being prepared by the committee.

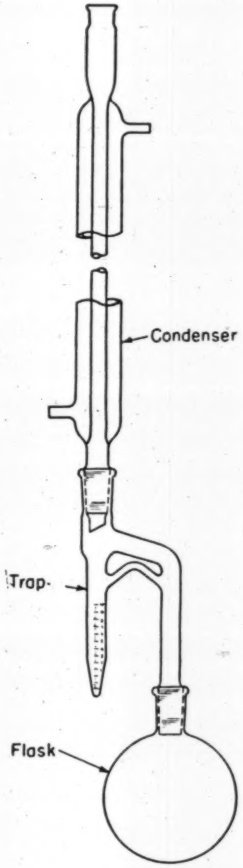

Condenser
Trap
Flask

FIG. 1.—Apparatus Assembly with Glass Flask.

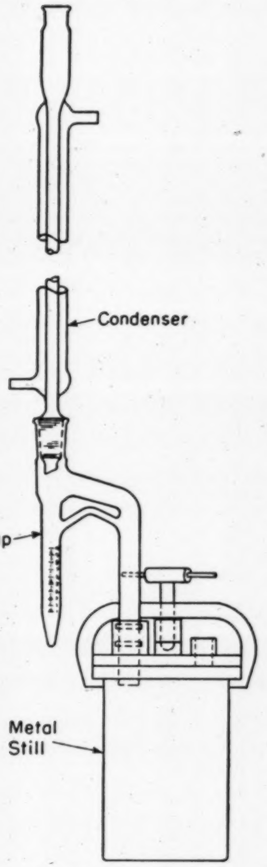

Condenser
Trap
Metal
Still

FIG. 2.—Apparatus Assembly with Metal Still.

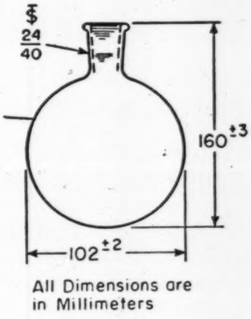
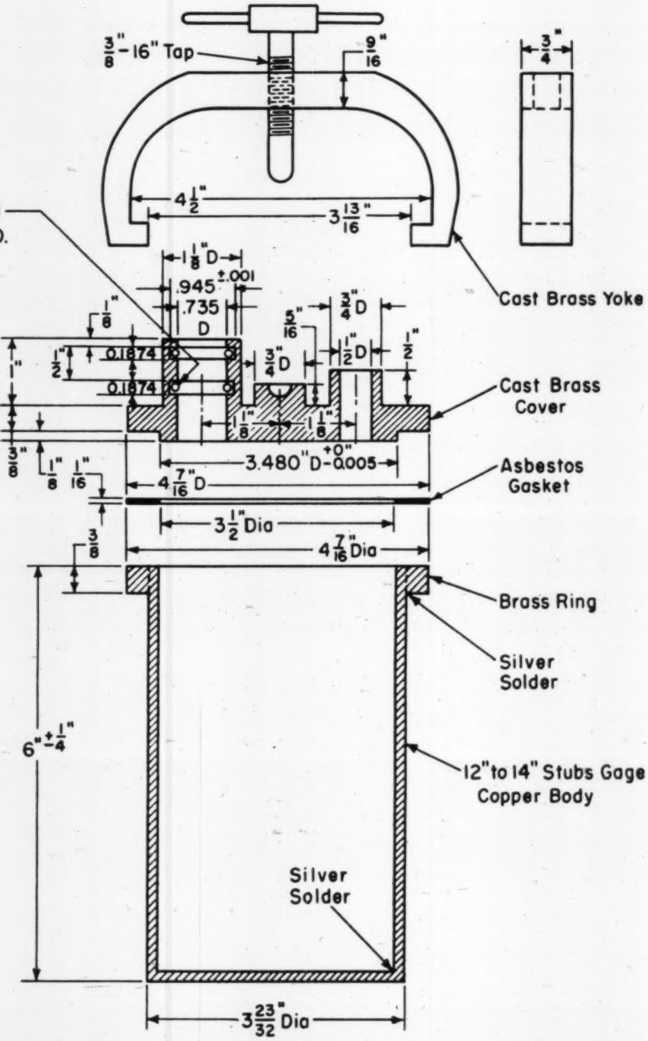
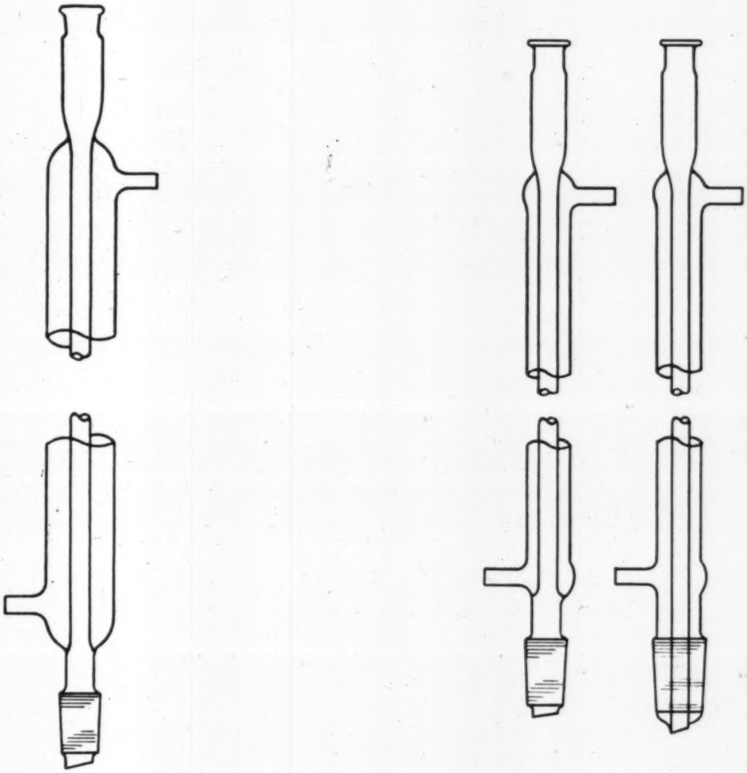

$
24
40
160±3
102±2
All Dimensions are
in Millimeters

FIG. 3.—Glass Flask, 500 ml.


$\frac{3}{8}$"-16" Tap
$\frac{9}{16}$"
$\frac{3}{4}$"
O-Rings
Two Required
1" O.D. x $\frac{3}{4}$" I.D.
$4\frac{1}{2}$"
$3\frac{13}{16}$"
Cast Brass Yoke
$1\frac{1}{8}$" D
.945 ±.001
.735 D
$\frac{1}{8}$"
0.1874
0.1874
1"
$\frac{1}{2}$"
$\frac{5}{16}$"
$\frac{3}{4}$" D
$\frac{3}{4}$" D
$\frac{1}{2}$" D
$\frac{1}{2}$"
$1\frac{1}{8}$"
$1\frac{1}{8}$"
Cast Brass Cover
$\frac{3}{8}$"
$\frac{1}{8}$"
$\frac{1}{16}$"
3.480" D +0" -0.005
$4\frac{7}{16}$" D
Asbestos Gasket
$3\frac{1}{2}$" Dia
$\frac{3}{8}$
$4\frac{7}{16}$" Dia
Brass Ring
Silver Solder
$6" \pm \frac{1}{4}$"
12" to 14" Stubs Gage Copper Body
Silver Solder
$3\frac{23}{32}$" Dia

NOTE.—The O-rings shall be 1 in. outside diameter and $\frac{3}{4}$ in. inside diameter. O-rings that have been found satisfactory are available from the Minnesota Rubber and Gasket Co., designated as No. 6627-15, compound 245A, having a durometer hardness of 70 ±5 on the Shore A scale.

FIG. 4.—Metal Still, Approximately 100 ml.

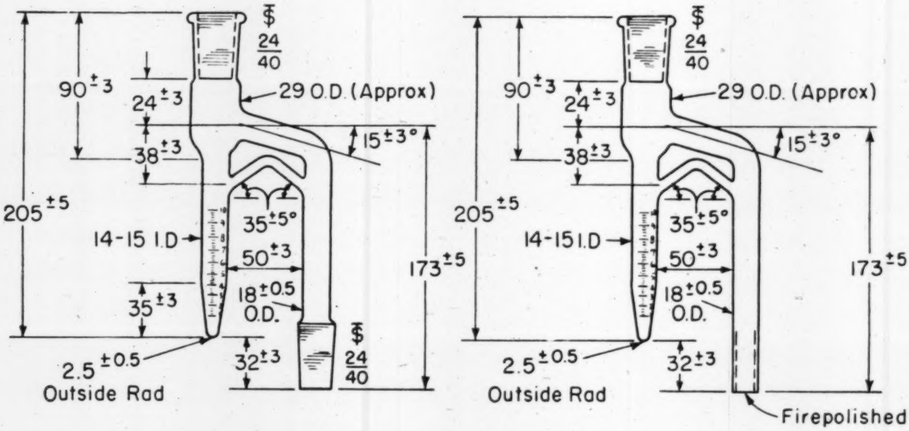


Liebig Condenser

West Condensers
(Alternate Designs)

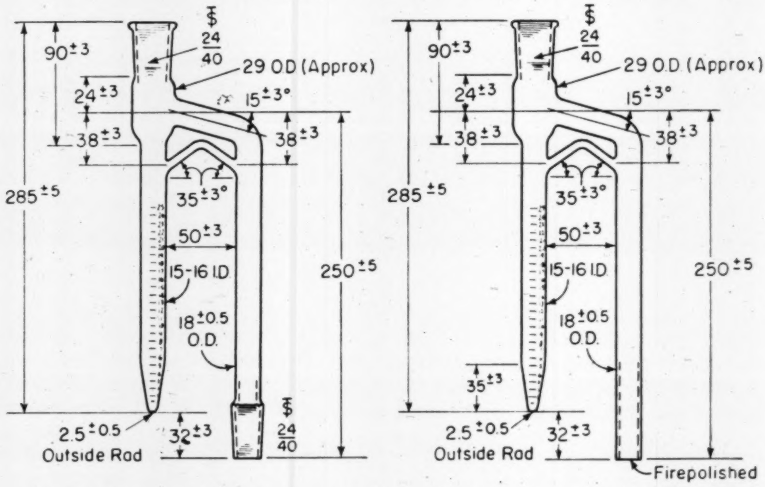
NOTE.—Ends of connections to water supply and drain may vary in design. Connection may be on same or opposite sides of jacket.

FIG. 5.—Condensers.


$ 24/40
29 O.D. (Approx)
90 ± 3
24 ± 3
38 ± 3
15 ± 3°
205 ± 5
35 ± 5°
14-15 I.D
50 ± 3
173 ± 5
18 ± 0.5 O.D.
35 ± 3
32 ± 3
2.5 ± 0.5 Outside Rad
Firepolished

All Dimensions are in Millimeters

FIG. 6.—Trap, 10 ml.


$ 24/40
29 O.D (Approx)
90 ± 3
24 ± 3
15 ± 3°
38 ± 3
285 ± 5
35 ± 3°
50 ± 3
15-16 I.D
250 ± 5
18 ± 0.5 O.D.
35 ± 3
2.5 ± 0.5 Outside Rad
32 ± 3
Firepolished

All Dimensions are in Millimeters All Dimensions are in Millimeters

FIG. 7.—Trap, 25 ml.

REPORT OF COMMITTEE E-2
ON
EMISSION SPECTROSCOPY*

Committee E-2 on Emission Spectroscopy held two meetings during the year: the first in Atlantic City, N. J., on June 30, 1953, and the second in Pittsburgh, Pa., on March 4, 1954. Meetings of the Advisory Committee were held in Atlantic City on June 28, 1953; in Rochester, N. Y., on October 17, 1953; and in Pittsburgh, Pa., on March 4, 1954.

The committee sponsored a symposium on Fluorescent X-ray Spectrographic Analysis on June 29, 1953, at the Annual Meeting of the Society in Atlantic City. The symposium is now available as ASTM publication STP No. 157.

The committee now consists of 122 members, which represents an increase of two members since the last annual report.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, J. Raynor Churchill.
Vice-Chairman, E. B. Ashcraft.
Secretary, Cyrus Feldman.

PUBLICATIONS

In the past year four publications sponsored by the committee have appeared in print as follows: (1) Symposium on Chemical Analysis of Inorganic Solids by Means of the Mass Spectrometer, Special Technical Publication No. 149, June, 1953; (2) Methods for Emission Spectrochemical Analysis, October, 1953; (3) Index to the Literature on Spectrochemical Analysis, Part III, 1946–1950, by B. F. Scribner and W. F. Meggers, Special Technical Publication No. 41-C, January, 1954; and (4) Symposium on Fluorescent X-ray Spectrographic Analysis, Special Technical Publication No. 157, February, 1954.

The book on methods is the culmination of work begun seven years ago to prepare and publish important spectrochemical methods in standardized form. The book includes 55 methods or practices covering the spectrochemical analysis of most of the commercial metals and alloys, and certain nonmetallic materials such as slags, ceramics, and caustic liquors. Four of the methods are tentative and the remainder are in suggested form; work is under way to advance many of the latter to tentative status.

The two symposia present authoritative papers on two important new fields of instrumental analysis.

The Index to the Literature by Scribner and Meggers is an extension of two earlier bibliographies issued by the ASTM. This series of bibliographies now covers the literature on emission spectrochemical analysis from 1920 through 1950. These four publications, which were sponsored by the committee and published by ASTM, represent a substantial contribution to the field of instrumental analysis and are a tribute to the efforts of the committee members. In addition to the many authors and reviewers in the committee who provided the material for the publications, special recognition should be made of the work of C. L. Guettel and K. O. Stevenson who contributed much of the editing of the book of methods, E. B. Ashcraft who arranged for the symposia and edited the two symposia publications, and finally the ASTM editorial offices for valued cooperation in bringing the material into print.

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13–18, 1954.

RECOMMENDATIONS ACCEPTED BY THE ADMINISTRATIVE COMMITTEE ON STANDARDS

Subsequent to the 1953 Annual Meeting, Committee E-2 presented to the Society through the Administrative Committee on Standards the following recommendations:

Tentative Method of:

Spectrochemical Analysis of Aluminum and Aluminum-Base Alloys by the Point-to-Plane Spark Technique (E 101 – 53 T).

Revision of Tentative Method of:

Spectrochemical Analysis of Zinc-Alloy Die Castings for Minor Constituents and Impurities (E 27 – 43 T), with a change in title to read "Tentative Method for Spectrochemical Analysis of Zinc-Base Alloys and High Grade Zinc by the Solution—D-C Arc Technique."

Withdrawal of Tentative Method of:

Spectrochemical Analysis of Zinc for Lead, Iron, and Cadmium (E 26 – 43 T).

These recommendations were accepted by the Standards Committee on September 9, 1953, and the new and revised tentative methods appear in the compilation of Methods for Emission Spectrochemical Analysis.

NEW TENTATIVE

A proposed Tentative Method for Spectrochemical Analysis of Tin by the Cast Pin - Spark Technique has been prepared for action by the Administrative Committee on Standards. The method is based on, and will supersede, the Suggested Method SM 6-9 with similar title which appears in the book on Methods for Emission Spectrochemical Analysis.

REVISION OF TENTATIVE

A proposed revision of the Tentative Method for the Spectrochemical Analysis of Tin Alloys for Minor Constituents and Impurities (E 51 – 43 T) has also been prepared for action by the Administrative Committee on Standards. The revision incorporates, together with Method E 51, the suggested Method SM 6-4 which appears in the book on Methods for Emission Spectrochemical Analysis.

ACTIVITIES OF SUBCOMMITTEES

The subcommittees of Committee E-2 were active during the year on standardization of fundamental procedures and analytical methods. The organization of the subcommittees remains unchanged from that of the last report except for a few changes in assignments of members. The principal activities of the subcommittees were as follows:

Subcommittee I on Apparatus and Equipment (R. G. Russell, chairman).—A new draft was prepared on Description and Specification of Spectrographic Equipment; this is now considered to be in final form. A report on testing of three photographic emulsions is in preparation.

Subcommittee II on Fundamental Methods (R. W. Smith, chairman).—Group 1 on Specification of Spark Generators, headed by R. A. Wolfe, has arranged a series of cooperative studies on the behavior of excitation sources. Group 2, headed by J. Sherman, has prepared a report on Precision and Accuracy which is to be circulated within the subcommittee. Group 4, headed by H. A. Tuttle, has prepared a draft of a tentative recommended practice in photography which is undergoing editorial review. Groups 5 and 7, headed by J. H. Coulliette and M. F. Hasler, are attempting to reconcile differing views in a new draft of a report on basic calculations in spectrographic analysis. Group 6, headed by D. L. Fry, is engaged in a cooperative testing program designed to test semi-quantitative methods of analysis.

Subcommittee III, Editorial (K. O. Stevenson, chairman).—Preparation has continued on a booklet of editorial instructions for the guidance of Committee E-2. Eight suggested methods and two tentative methods were reviewed during the year.

Subcommittee IV on Standard Samples and Pure Materials (G. A. Nahstoll, chairman).—Work toward standardization of graphite electrode sizes has continued and the results of a survey of users are being compiled.

Subcommittee V on Copper, Nickel, and Their Alloys (E. K. Jaycox, chairman).—Group 1, headed by A. W. Young, has prepared a proposed method for sampling molten copper-base alloys which is to be circulated in the subcommittee. The subcommittee worked closely with Subcommittee VIII-A of Committee B-4 on cooperative tests of a method for the analysis of cathode nickel. The results of these tests will be considered in rewriting Method SM 5-1 in the form of a tentative.

Subcommittee VI on Lead, Tin, Antimony, Bismuth, and Their Alloys (E. J. Dunn, Jr., chairman).—Two proposed tentative methods for the analysis of tin alloys, based on suggested methods SM 6-4 and SM 6-9, have been approved by the subcommittee and forwarded to Committee E-2 for action. Cooperative tests of suggested method SM 6-3 on the analysis of pig lead was started in a group of five laboratories. Two suggested methods were reviewed.

Subcommittee VII on Aluminum, Magnesium, and Their Alloys (J. R. Churchill, chairman).—Five suggested methods were reviewed during the year for analysis of titanium, aluminum, and aluminum oxide.

Subcommittee VIII on Zinc, Cadmium, and Their Alloys (Alan Goldblatt, chairman).—A proposed tentative method for the analysis of zinc alloys by spark excitation was reviewed and rewritten.

Subcommittee IX on Ferrous Metals (P. R. Irish, chairman).—A draft of a tentative method for the analysis of steel and cast iron was completed except for data on precision and accuracy. A suggested method for the analysis of stainless steel was reviewed.

Subcommittee X on Non-Metals (W. J. Poehlman, chairman).—This subcommittee has been especially active during the year through most of its eleven task groups which are collecting and reviewing methods for the analysis of a wide variety of materials. These include alkalies, ceramics, ores, slags, and refractories. Three tentative methods are being prepared for the analysis of caustic liquors, ceramics, and slags. Nine suggested methods are being reviewed by the subcommittee.

This report has been submitted to letter ballot of the committee, which consists of 122 members; 77 members returned their ballots, of whom 75 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

B. F. SCRIBNER,
Chairman.

J. H. COULLIETTE,
Secretary.

REPORT OF COMMITTEE E-3

ON

CHEMICAL ANALYSIS OF METALS*

Committee E-3 on Chemical Analysis of Metals held one meeting during the year: at the Annual Meeting of the Society on July 1, 1954, at Atlantic City, N. J. At the present time the committee consists of 115 members.

With the new edition of the ASTM Methods for Chemical Analysis of Metals contemplated for late this year, particular emphasis of the committee's work has been on refining the present methods, introducing new methods for ferro alloys, and providing for titanium alloy elements.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, Arba Thomas.

Vice-Chairmen, J. L. Hague and Clarence Zischkau.

Secretary, H. Kirtchik.

TENTATIVES CONTINUED WITHOUT REVISION

Committee E-3 is currently reviewing the following seventeen tentative methods that have stood for two years or more without change, with the idea of making revisions, additions, and combinations before the methods are published in the next edition of the Book of ASTM Methods for Chemical Analysis of Metals. The committee recommends that for the present they be continued as tentative without revision:

Tentative Methods for:

Chemical Analysis of Pig Lead (E 37 – 50 T),
Chemical Analysis of Lead- and Tin-Base Solder Metal (E 46 – 50 T),
Chemical Analysis for Aluminum in Zinc-Base Die-Casting Alloys (E 47 – 50 T),
Chemical Analysis for Sulfur in Special Brasses and Bronzes (E 54 – 50 T),
Chemical Analysis of White Metal Bearing Alloys (E 57 – 50 T),
Polarographic Determination of Lead and Cadmium in Zinc (E 68 – 46 T),
Chemical Analysis of Copper-Nickel and Copper-Nickel-Zinc Alloys (E 75 – 50 T),
Chemical Analysis of Nickel-Copper Alloys (E 76 – 50 T),
Chemical Analysis of Antimony Metal (E 86 – 50 T),
Sampling Non-Ferrous Metals and Alloys in Cast Form for Determination of Chemical Composition (E 88 – 50 T).

Photometric Methods for:

Chemical Analysis of Aluminum-Base Alloys (E 34 – 50 T),[1]
Determination of Cobalt in Nickel (E 39 – 49 T),
Chemical Analysis of Magnesium and Magnesium-Base Alloys (E 35 – 50 T),
Chemical Analysis of Copper and Copper-Base Alloys (E 62 – 50 T),
Determination of Iron in Slab Zinc (Spelter) (E 64 – 50 T),
Chemical Analysis of Lead, Tin, Antimony, and Their Alloys (E 87 – 50 T).[1]

Recommended Practice for:

Photometric Methods for Chemical Analysis of Metals (E 60 – 50 T).

ACTIVITIES OF SUBCOMMITTEES

Division F on Ferrous Metals (Arba Thomas, chairman).—Considerable progress was made by the majority of the task groups during the year.

A method for the volumetric determination of silicon in ferrotungsten and tungsten metal, developed by the ferro-alloy task group, was approved by letter ballot of both Division F and Committee E-3 and is being presented to the Administrative Committee on Standards for publication as tentative together with methods for the analysis of ferrotitanium.[1] Considerable progress has been made on the development of methods for the analysis of ferroboron, and in all probability this work will be completed during the early part of the coming year.

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13–18, 1954.

[1] See Editorial Note, p. 565.

A new photometric method for manganese in steel has also been approved by letter ballot of both Division F and Committee E-3 and is being submitted to the Administrative Committee on Standards for publication as tentative.[1] This procedure was designed to be applicable to both plain carbon steel and low-alloy steels.

The task force responsible for methods covering high-silicon electrical steels has made considerable progress during the year. Work has been practically completed on modifications of the majority of the present Methods E 30 so that they will include these high-silicon steels. Several photometric methods are being considered by the task force for the determination of phosphorus, aluminum, and certain other elements in these steels.

The task force responsible for methods for the determination of magnesium in nodular iron has obtained encouraging data on the proposed methods that have been studied to date. Additional studies will have to be made in order to obtain more definite data on the reproducibility and accuracy of the proposed methods. It is anticipated that a satisfactory tentative method will be ready sometime during the coming year.

A tentative procedure for the determination of sulfur in cast iron, plain carbon steel, and low-alloy steel by combustion has been developed by the task force responsible for this project. This proposed tentative procedure is now being studied for reproducibility and accuracy, and in all probability this method will be ready for letter ballot during the coming year.

The task force in charge of the development of methods for the determination of columbium and tantalum in stainless steels has a photometric procedure under study. This method covers the direct photometric determination of these two elements, eliminating the calculation of one of the elements by difference.

A method for the determination of cobalt in high-alloy steels is being studied by the task group responsible for this project. The task group in charge of the development of a method for the determination of zirconium in steels is now studying a procedure utilizing *p*-brommandelic acid.

The task group responsible for the development of a method for the determination of aluminum in alloy steels of the stainless types has made very little progress during the year. During the coming year an attempt will be made to revitalize this task group in order to expedite this program.

At the June, 1953, meeting of the division a task force was formed under the chairmanship of E. A. Lucas to study methods for the determination of rare earth elements in steels treated with these elements. The first approach to this problem will probably be to establish a satisfactory method for the determination of total rare earths. When this has been accomplished, procedures for the separation of the individual elements will be considered if this is deemed advisable.

In an effort to expedite the consideration of photometric methods for the determination of many elements in steels, a new task force responsible for this project was appointed under the chairmanship of M. D. Cooper.

Division N on Non-Ferrous Metals (C. Zischkau, chairman).—After considerable study and discussion it was voted to disband the subcommittee structure of the division and to operate on a task-force basis. An advisory group, comprising former subcommittee chairmen, was appointed to assist in the allocation of task-force assignments.

Methods for the analysis of beryllium copper alloys are ready for publication,[1] and methods for the analysis of fire-refined copper and chromium copper are being studied.

Editorial revisions are being made to some of the white-metal methods, along with an improved revision of the photometric arsenic procedure.[1] A photometric antimony method is being studied.

A method for the photometric determination of silicon in aluminum alloys is ready for publication.[1]

Methods have been written and approved for the determination of copper, magnesium, and lead in zinc and zinc-base alloys.

A new procedure for the determination of cadmium in silver solder is being tested and these methods will be rewritten and modernized.

A group of six methods for the analysis of impurities in electronic nickel has been completed and tested in cooperation with a group from Committee B-4 on Electrical Heating, Resistance, and Related Alloys. These are ready for committee letter ballot.[1]

Further study is being made on the photometric determination of zirconium in magnesium-base alloys.

Division S on Sampling (J. P. Brull, chairman).—Subcommittee S-1 has been relatively inactive and would welcome any problems regarding sampling of ferrous metals. Copies of a study on the segregation of sulfur in cast iron have been distributed.

Subcommittee S-2 on Sampling of the Non-Ferrous Metals plans to rewrite the Methods of Sampling Non-Ferrous Metals and Alloys in Cast Form for Determination of Chemical Composition (E 88 - 50 T) in the light of comments received. Until this task can be completed, the subcommittee recommends that Methods E-88 be continued as tentative.

The division has appointed three members to work in cooperation with Committee E-2 on Emission Spectroscopy, on the development of a joint sampling procedure.

One member of Division S has been appointed to a special task force to review methods of analyses for metal powders, prepared by Committee B-9.

A member of Division S has been appointed to Committee B-2 in regard to the sampling procedures for titanium metal.

Division M on Miscellaneous Metals (R. M. Fowler, chairman).—During the year, progress has been made in the development of methods for the analysis of titanium metal through cooperation with the group at Watertown Arsenal studying this problem. While no methods have developed to the tentative status, several should reach this stage by the end of the year. In the development of analytical methods for titanium, the problem of sampling and the preparation of suitable standard samples appears to be more difficult than the development of satisfactory methods of analysis.

A task group has been organized and has started work on the revision of the procedures for the analysis of electrical heating alloys.

Division G on General Analytical Methods (H. F. Beeghly, chairman).—Subcommittee G-1 on Reagents has consulted with interested groups on reagent specifications.

Subcommittee G-2 on Apparatus has prepared a final draft on performance specifications on analytical balances and forwarded it to Subcommittee 21 of Committee E-1 for review prior to initiating appropriate action for its acceptance as a tentative specification. Also, preparation of the initial draft of performance specifications on electrodeposition apparatus is under way.

Subcommittee G-3 on Common Procedures has prepared a procedure for nickel. A task force, using this procedure, is analyzing a steel sample to obtain comparative data with the method. Members of G-3 met with representatives of Divisions F and N to discuss a revision of the periodate method for manganese.

Editorial Subcommittee (J. L. Hague, chairman).—One meeting was held during the year for the purpose of reviewing the fourth draft covering the Recommendations on Form for ASTM Methods for Chemical Analysis of Metals.

This report has been submitted to letter ballot, which consists of 115 members; 83 members returned their ballots, of whom 78 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

J. W. STILLMAN,
Chairman.

H. KIRTCHIK,
Secretary.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee E-3 presented to the Society through the Administrative Committee on Standards the following recommendations:

Tentative Methods for:
- Chemical Analysis of Ferro-Alloys (E 31 - 54 T), and
- Chemical Analysis of Copper-Beryllium Alloys (E 106 - 54 T).

Tentative Photometric Methods for:
- Determination of Manganese in Steel (E 30 - 54 T), and
- Chemical Analysis of Electronic Nickel (E 107 - 54 T).

Revision of Tentative Photometric Methods for:
- Chemical Analysis of Aluminum and Aluminum-Base Alloys (E 34 - 50 T), and
- Chemical Analysis of Lead, Tin, Antimony, and Their Alloys (E 87 - 50 T).

The revision of Methods E 34 was accepted by the Standards Committee on December 22, 1954, and the other recommendations were accepted on October 4, 1954; all will appear in the 1955 Book of ASTM Methods for Chemical Analysis of Metals.

REPORT OF COMMITTEE E-4

ON

METALLOGRAPHY*

Committee E-4 on Metallography and most of its subcommittees held two meetings during the current year: the first in Atlantic City, N. J., on June 30, 1953, and the second in Washington, D. C., on February 2, 1954.

The committee continues a steady growth and now has 108 members.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, L. L. Wyman.
Vice-Chairman, R. E. Penrod.
Secretary, Mary R. Norton.

Recommendations Accepted by the Administrative Committee on Standards

Subsequent to the 1953 Annual Meeting, Committee E-4 presented to the Society through the Administrative Committee on Standards revisions of the Tentative Method for Preparing Quantitative Pole Figures of Metals (E 81 – 49 T). This recommendation was accepted by the Standards Committee on March 3, 1954, and the revised method appears in the 1954 Supplement to Book of ASTM Standards, Part 2.

Activities of Subcommittees

Subcommittee I on Selection and Preparation of Samples (F. C. Hull, chairman) has a number of Task Groups working on the many sections of the Methods of Preparation of Metallographic Specimens (E 3 – 46 T). The many advances in metallographic technique make the present revision a major task, and it is hoped that most of the work can be completed within the next year.

Subcommittee II on Definitions (R. S. Busk, chairman) has completed the few changes recommended in the final review of the nearly 1000 definitions compiled by the subcommittee. The entire compilation is now ready for letter ballot.

Subcommittee III on Nomenclature (P. A. Beck, chairman) has devised what appears to be an excellent system of phase nomenclature for metallic systems. The proposal is now undergoing extensive review, both in this country and abroad.

Subcommittee IV on Photomicrography (S. W. Poole, chairman) has been particularly active in connection with the 1954 Photomicrographic Exhibit. Particular emphasis on student and foreign representation has involved a very appreciable amount of contact work, and preliminary results are promising.

A new phase of this effort is that the student contest involves all stages of work from the raw specimen to completed photomicrograph. The samples, alloy steel and aluminum alloy, are furnished the students through the courtesy of Committee E-4 members.

Subcommittee V on Microhardness is continuing the "round-robin" series of interlaboratory tests using specially calibrated stage micrometers. In addition, a new series of tests is being inaugurated which is aimed at evaluating the effects of various methods of surface preparation on microhardness determinations.

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13–18, 1954.

Subcommittee VI on X-ray Diffraction (W. L. Fink, chairman) prepared the revision of Method E 81 which was accepted during the year by the Administrative Committee on Standards. In addition, the first section of the proposed enlarged Recommended Practice E 43 has already had one review and now appears ready for final letter ballot of the subcommittee.

Subcommittee VII on Thermal Analysis (D. I. Finch, chairman) is taking preliminary steps to formulate a recommended practice for thermal analysis by means of change in electrical resistance.

Subcommittee VIII on Grain Size (R. E. Penrod, chairman) is making a thorough check of the two non-ferrous grain size standards and, in collaboration with Section C on Non-Ferrous Grain-Size (H. P. George, chairman), will eliminate all minor discrepancies in all of the grain size standards as a near-final step to the consolidation of all of these methods.

Subcommittee XI on Electron Microstructure (W. L. Grube, chairman) has taken a major forward step by extending its interests and activities to the field of non-ferrous metals. The original group interested in electron microstructure of steels will continue as one section of the subcommittee, and a new section concerned with non-ferrous metals will be organized.

The subcommittee's most interesting symposium on Techniques for Electron Metallography held at the 1953 Annual Meeting was exceptionally well received, and is the basis for the currently available STP No. 155.

The Fourth Progress Report of Subcommittee XI is appended to this report.[1]

This report has been submitted to letter ballot of the committee, which consists of 108 members; 90 members returned their ballots, of whom 84 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

L. L. WYMAN,
Chairman.

MARY R. NORTON,
Secretary.

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[1] See p. 568.

APPENDIX

ELECTRON MICROSTRUCTURE OF TEMPERED BAINITE AND TEMPERED MARTENSITE IN STEEL

FOURTH PROGRESS REPORT BY SUBCOMMITTEE XI OF COMMITTEE E-4*

The first two reports[1, 2] of Subcommittee XI of Committee E-4 on Metallography presented the results of a cooperative electron microscope study of structures of a series of eutectoid steel samples. Microstructures of isothermally transformed bainites, and of quenched - and - tempered martensites, were examined. Electron micrographs of these specimens indicated that the microstructure in those bainites formed above 600 F differed markedly from that in the bainites formed at or below 600 F. It was therefore concluded that these bainites could be grouped into two classes: upper bainite and lower bainite. The electron micrographs also indicated that there was a similarity between some of the bainites and the tempered martensites.

In view of these results, the committee decided to study the relationships between bainitic and martensitic structures and, in particular, to compare these structures after each had received the same tempering treatment. Chosen for this investigation were bainites produced by isothermal transformation at 500 F and 750 F, and quenched martensite. These structures were examined both as formed and after tempering at 800 F, 1100 F, and 1250 F.

EXPERIMENTAL WORK

The specimens were prepared from

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* Members of Subcommittee XI actively participating in this study:

W. L. Grube, *Chairman*—General Motors Corp., Detroit, Mich.
C. M. Schwartz, *Secretary*—Battelle Memorial Inst., Columbus, Ohio
L. S. Birks, Naval Research Laboratory, Washington, D. C.
P. Coheur, Centre Belge de Metallurgie Physique, Liege, Belgium
A. L. Ellis, International Harvester Co., Chicago, Ill.
R. M. Fisher, U. S. Steel Corp., Kearny, N. J.
E. F. Fullam, Ernest F. Fullam, Inc., Schenectady, N. Y.
A. H. Geisler, General Electric Co., Schenectady, N. Y.
D. J. Girardi, Timken Roller Bearing Co., Canton, Ohio
L. Habraken, Centre Belge de Metallurgie Physique, Liege, Belgium
J. M. Hodge, U. S. Steel Corp., Pittsburgh, Pa.
G. Noakes, Ford Motor Co., Dearborn, Mich.
W. Pahl, Ford Motor Co., Dearborn, Mich.
L. D. Pellier, American Cyanamid Co., Stamford, Conn.
G. E. Pellissier, U. S. Steel Corp., Pittsburgh, Pa.
G. H. Robinson, General Motors Corp., Detroit, Mich.
S. T. Ross, Chrysler Corp., Detroit, Mich.
F. G. Rowe, American Cyanamid Co., Stamford, Conn.
D. M. Teague (*Past Chairman*), Chrysler Corp., Detroit, Mich.
C. F. Tufts, Sylvania Electric Products, Bayside, L. I., N. Y.
J. R. Vilella, U. S. Steel Corp., Kearny, N. J.

[1] "Electron Microstructure of Steel," First Progress Report by Subcommittee XI on Electron Microstructure of Steel, ASTM Committee E-4 on Metallography, *Proceedings*, Am. Soc. Testing Mats., Vol. 50, p. 444 (1950).

[2] "Electron Microstructure of Bainite in Steel," Second Progress Report by Subcommittee XI of Committee E-4, *Proceedings*, Am. Soc. Testing Mats., Vol. 52, p. 543 (1952).

the same steel used in previous studies. The composition is as follows:

Carbon, per cent	0.87
Manganese, per cent	0.44
Silicon, per cent	0.17
Phosphorus, per cent	0.013
Sulfur, per cent	0.006
Nickel, per cent	0.39
Chromium, per cent	0.21

Sets of identical specimens were heat-treated at the Research Laboratory of the U. S. Steel Corp. The specimens were copper plated and austenitized in a reducing atmosphere for 35 min at 1800 F. Table I gives the further heat treatments of the specimens and also the Rockwell C hardness values.

TABLE I.—STRUCTURES INVESTIGATED AND CORRESPONDING HEAT TREATMENTS.

Specimen	Structure	Heat Treatment After Austenitizing	Hardness, R_c
5	Bainite formed at 500 F	2½ hr at 500 F	57.4
22	Bainite formed at 500 F, tempered at 800 F	2½ hr at 500 F, 1 hr at 800 F	47.7
35	Bainite formed at 500 F, tempered at 800 F	2½ hr at 500 F, 3 hr at 800 F	44.5
36	Bainite formed at 500 F, tempered at 800 F	2½ hr at 500 F, 6 hr at 800 F	43.5
23	Bainite formed at 500 F, tempered at 1100 F	2½ hr at 500 F, 1 hr at 1100 F	34.2
24	Bainite formed at 500 F, tempered at 1250 F	2½ hr at 500 F, 12 hr at 1250 F	16.5
4	Bainite formed at 750 F	6 sec at 550 F, 7 min at 750 F	43.8
25	Bainite formed at 750 F, tempered at 800 F	6 sec at 550 F, 10 min at 750 F, 1 hr at 800 F	42.5
26	Bainite formed at 750 F, tempered at 1100 F	6 sec at 550 F, 10 min at 750 F, 1 hr at 1100 F	33.2
27	Bainite formed at 750 F, tempered at 1250 F	6 sec at 550 F, 10 min at 750 F, 12 hr at 1250 F	18.5
9	Martensite, tempered at 800 F	Brine-quenched, 1 hr at 800 F	44.1
37	Martensite, tempered at 800 F	Brine-quenched, 6 hr at 800 F	45.0
10	Martensite, tempered at 1100 F	Brine-quenched, 1 hr at 1100 F	32.6
11	Martensite, tempered at 1250 F	Brine-quenched, 12 hr at 1250 F	20.1

The procedure used in the preparation of electron micrographs is similar to that described in previous progress reports[3, 4] and consists of the following steps:

Polish.—Mechanical.

Etch.—Picral, 2 to 4 per cent.

Replica.—Formvar or collodion, negative.

Shadowing Metal.—Chromium, shadowing angle 1:1 to 2:1.

Print.—Direct enlargement of negative plate.

RESULTS

Bainites Formed at 500 F:

The first series of micrographs, Figs. 1 to 8, is of lower bainites that were formed isothermally at 500 F and which received the temper as indicated in Table I. The series shows, as expected, that with increasing tempering temperature and time the carbides become coarser and more spheroidal, while the

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[3] Appendix to "Electron Microstructure of Steel," First Progress Report by Subcommittee XI.

[4] "Techniques for Ferrous Electron Metallography," Third Progress Report by Subcommittee XI of Committee E-4, *Proceedings*, Am. Soc. Testing Mats., Vol. 53, p. 505 (1953).

ratio of carbide to ferrite remains relatively unchanged. In general, the agglomeration of the carbides is accompanied by a decrease in hardness (Table I).

Figure 1 is typical of the fine, featherlike structure observed in lower bainite (57.4 R_c). The bainite "needles" contain small parallel platelets which are inclined to the needle axis; the needles are long and narrow. When this structure is tempered for 1 hr at 800 F, the over-all acicular appearance remains essentially unchanged, as shown in Fig. 2 (47.7 R_c). The parallel arrangement of the carbide platelets within the needles is similar to that in the untempered structure, although the carbides seem to be more clearly defined in the tempered structure.

Careful examination of Figs. 1 and 2, however, indicates some difference in the etching characteristics of the matrix. Comparison of the untempered and tempered structures at appreciably higher magnification, 30,000 ×, shows this difference between the two structures more distinctly (Figs. 3 and 4). Whereas the matrix in the tempered specimen is smooth and uniformly etched ferrite (Fig. 4), the matrix in the untempered specimen etches unevenly (Fig. 3). This appearance strongly suggests the presence of an extremely fine precipitate distributed in the matrix, in addition to the larger, more clearly defined carbide platelets. There is some reason to think that this fine constituent may actually be the hexagonal epsilon carbide described by K. H. Jack,[5] since earlier work by Austin and Schwartz[6] has shown that the untempered specimen contains epsilon carbide as well as cementite. This difference in the matrix probably accounts for the relatively large decrease in hardness (from 57.4 to 47.7 R_c) that occurs upon tempering for one hour at 800 F, since the change in the particle size of the cementite is not pronounced. The very fine structure in untempered lower bainite requires further investigation before its full significance can be evaluated.

Figure 5 (44.5 R_c) and Fig. 6 (43.5 R_c) are micrographs of the 500 F bainite, tempered at 800 F for 3 hr and 6 hr, respectively. They indicate that upon tempering the finer carbides tend to disappear, with a slight growth of the larger particles. The corresponding decrease in hardness is small.

The microstructure of 500 F bainite tempered for 1 hr at 1100 F is shown in Fig. 7 (34.2 R_c). There appears to be a dual size distribution of carbide particles in this structure; the smaller carbides are randomly distributed in the matrix, whereas the larger carbides are located predominately at the ferrite grain boundaries. Figure 8 (16.5 R_c) is an electron micrograph of 500 F bainite tempered for 12 hr at 1250 F. In this microstructure, the spheroidization and agglomeration of the carbides have reached an advanced stage; the larger carbide particles tend to have an angular shape, and they are situated at ferrite grain boundaries. The size and shape of the ferrite grains suggest that they are a vestige of the original bainite needles. These ferrite grains are considerably smaller than the prior austenite grains.

Bainites Formed at 750 F:

The second series of microstructures consists of electron micrographs of bainites which were formed at 750 F, chosen to be typical of upper bainite. Figure 9 (43.8 R_c) shows the microstructure of untempered 750 F bainite. The structure is coarser, the carbides are more randomly oriented than in the untempered 500 F bainite, and the acicularity is less marked. The carbides are much longer, more stringer-like, and tend to lie parallel to the longer axis of the bainite needle. Tempering this structure for 1 hr at 800 F, Fig. 10 (42.5 R_c), results in little change of the microstructure or the hardness.

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[5] K. H. Jack, "Results of Further X-ray Structural Investigations of the Iron-Carbon and Iron-Nickel Systems and of the Related Interstitial Alloys," *Acta Crystallographica*, Vol. 3, p. 392 (1950).

[6] A. E. Austin and C. M. Schwartz, "Electron Diffraction Study of Iron-Carbide in Bainite and Tempered Martensite," *Proceedings*, Am. Soc. Testing Mats., Vol. 52, p. 592 (1952).

The microstructure of the 750 F bainite tempered for 1 hr at 1100 F, Fig. 11 (33.2 R_c), is generally similar to that of the 500 F bainite tempered in the same way, except that some of the long, stringer-like carbide particles characteristic of upper bainite persist in this tempered structure. After tempering the 750 F bainite for 12 hr at 1250 F, Fig. 12 (18.5 R_c), the microstructure is again similar to that of the 500 F bainite after the same tempering treatment, although in the tempered 750 F bainite the ferrite grain size is somewhat larger and the grains less elongated.

Tempered Martensites and Comparison with Tempered Bainites:

The third series of micrographs consists of martensites which have been tempered at 800 F, 1100 F, and 1250 F. These structures were discussed in the First Progress Report of the Subcommittee[1] and are included here for comparison with the tempered bainites described above.

Figure 13 (44.1 R_c) is a micrograph of martensite tempered 1 hr at 800 F. The carbide size and distribution is very similar to that found in 750 F bainite, both untempered (Fig. 9) and tempered at 800 F for 1 hr (Fig. 10). Figure 14 (45.0 R_c) is a micrograph of martensite tempered 6 hr at 800 F. After this longer tempering treatment at 800 F, the carbides are somewhat coarser, but otherwise the structure remains unchanged.

The structure of martensite tempered 1 hr at 1100 F is shown in Fig. 15 (32.6 R_c). The carbide size and distribution is very similar to that observed in the 500 F bainite and 750 F bainite after the same tempering treatment, except for the presence of some long, stringer-like carbides in the tempered 750 F bainite.

Figure 16 is an electron micrograph of martensite tempered 12 hr at 1250 F (20.1 R_c). The carbide size and distribution in this microstructure is much the same as in the corresponding tempered bainites. There are, however, apparent differences in ferrite grain size and shape among these three microstructures. In the tempered 750 F bainite, the ferrite grains are relatively large and somewhat equi-axed; in the tempered 500 F bainite, they are elongated and smaller; and in the tempered martensite, they are equi-axed and still smaller.

CONCLUSIONS

1. The matrix in the as-formed 500 F bainite shows a characteristic roughness which suggests the existence of a fine precipitate in addition to the cementite platelets. Upon tempering 1 hr at 800 F, this roughness disappears and the matrix becomes smooth.

2. Vestiges of the original bainite and martensite structures are retained after tempering. In 500 F bainite the characteristic cross-striated needle structure remains after tempering for 1 hr at 800 F, and after prolonged tempering at 1250 F elongated ferrite grains, reminiscent of the original bainite needles, are observed.

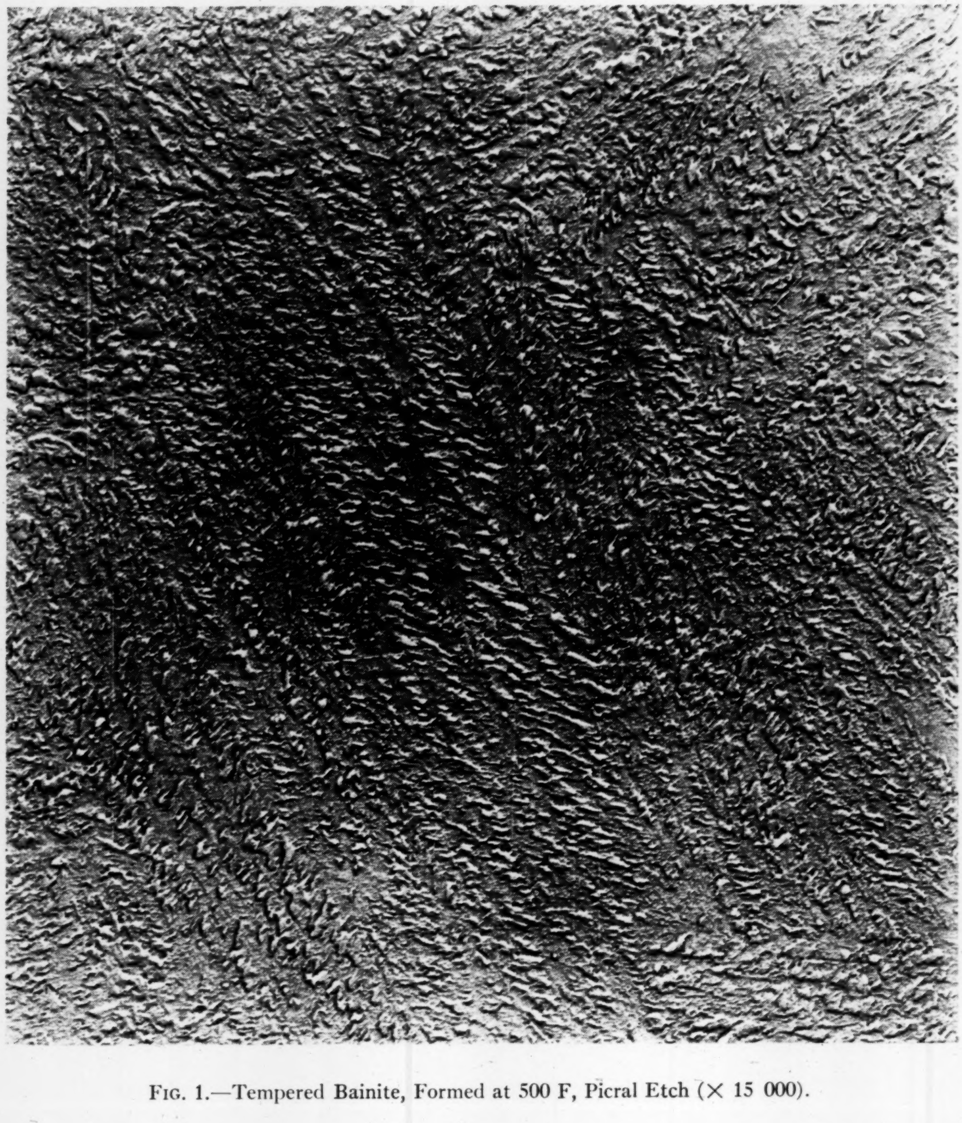

FIG. 1.—Tempered Bainite, Formed at 500 F, Picral Etch (× 15 000).

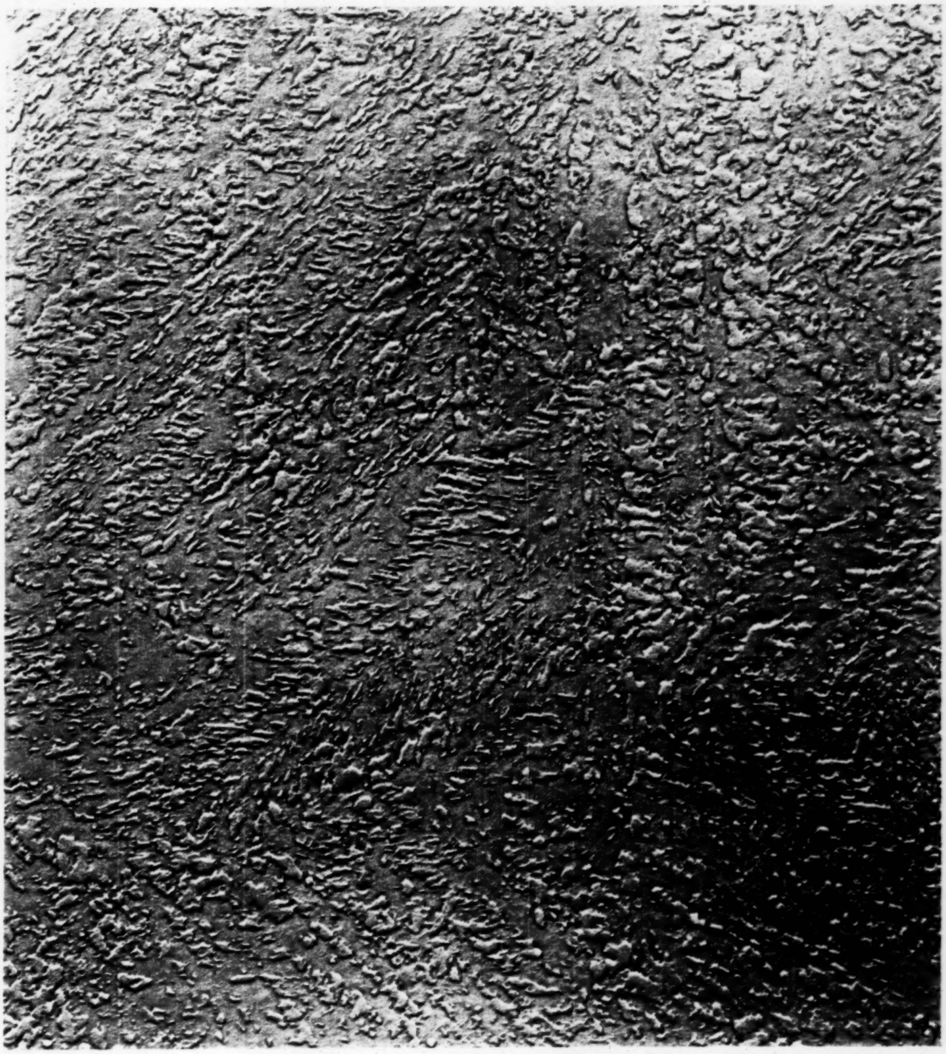

FIG. 2.—Tempered Bainite, Formed at 500 F, Tempered 1 hr at 800 F, Picral Etch (× 15 000).

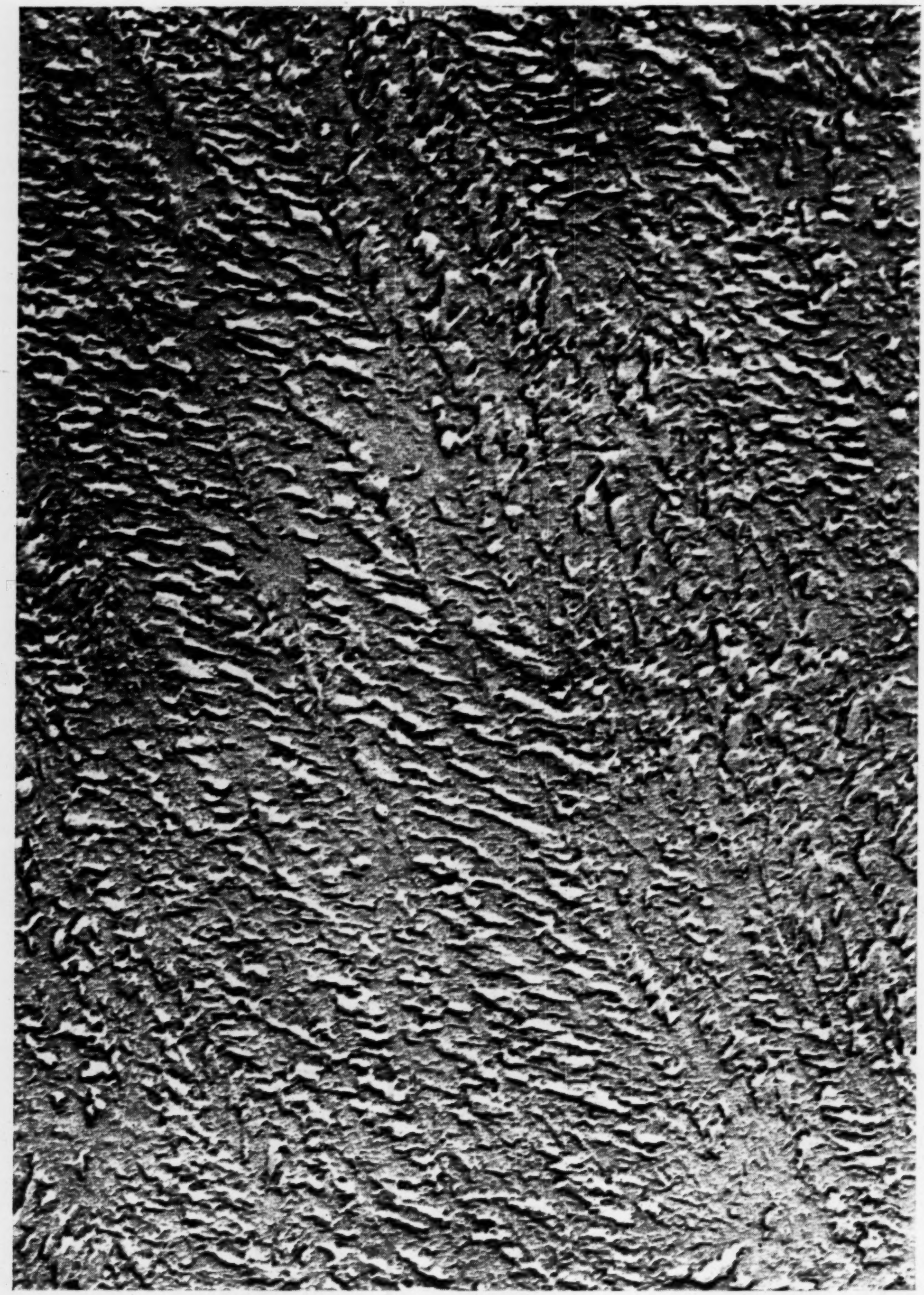

FIG. 3.—Tempered Bainite, Formed at 500 F, Picral Etch (× 30 000).

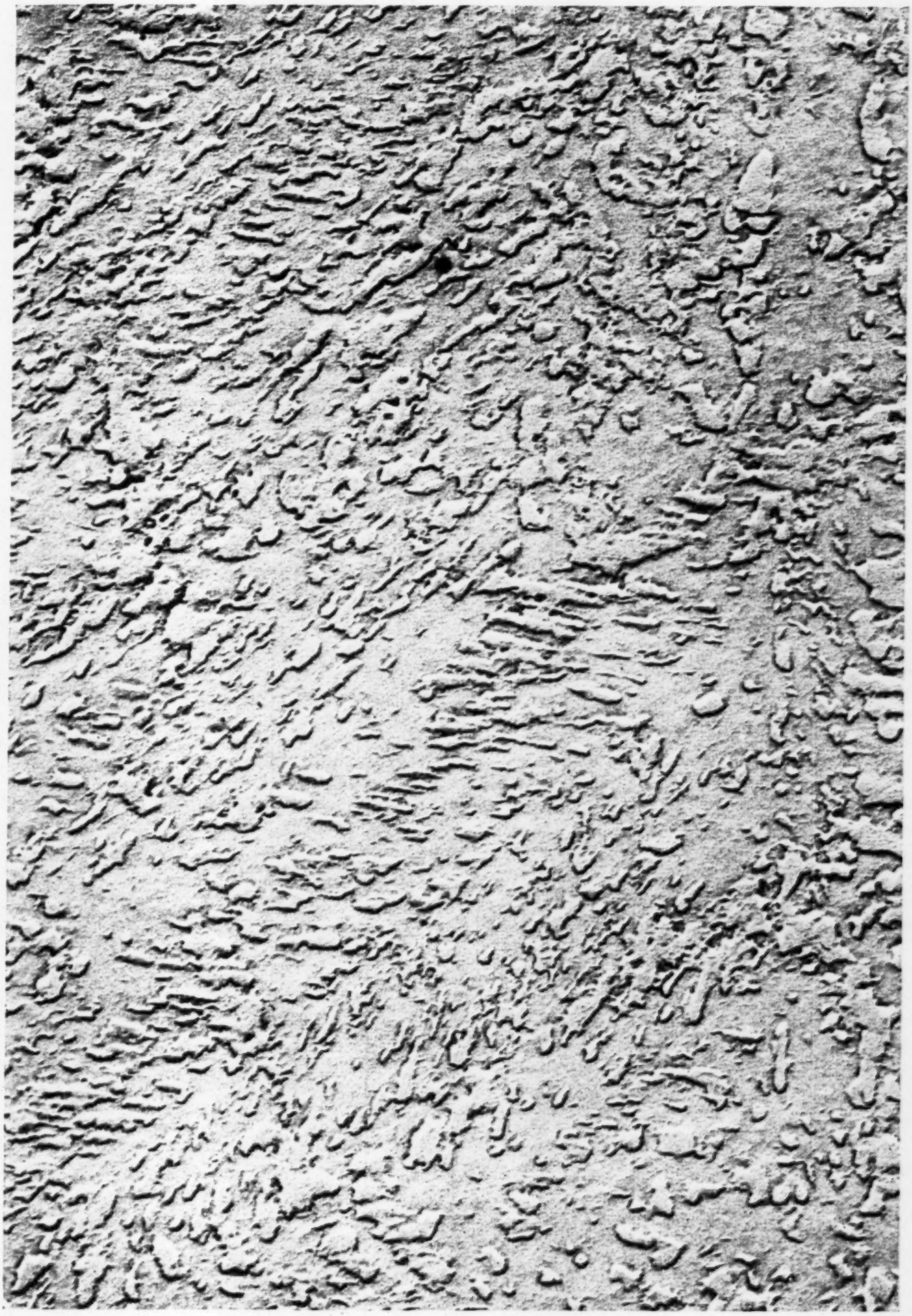

FIG. 4.—Tempered Bainite, Formed at 500 F, Tempered 1 hr at 800 F, Picral Etch (× 30 000).

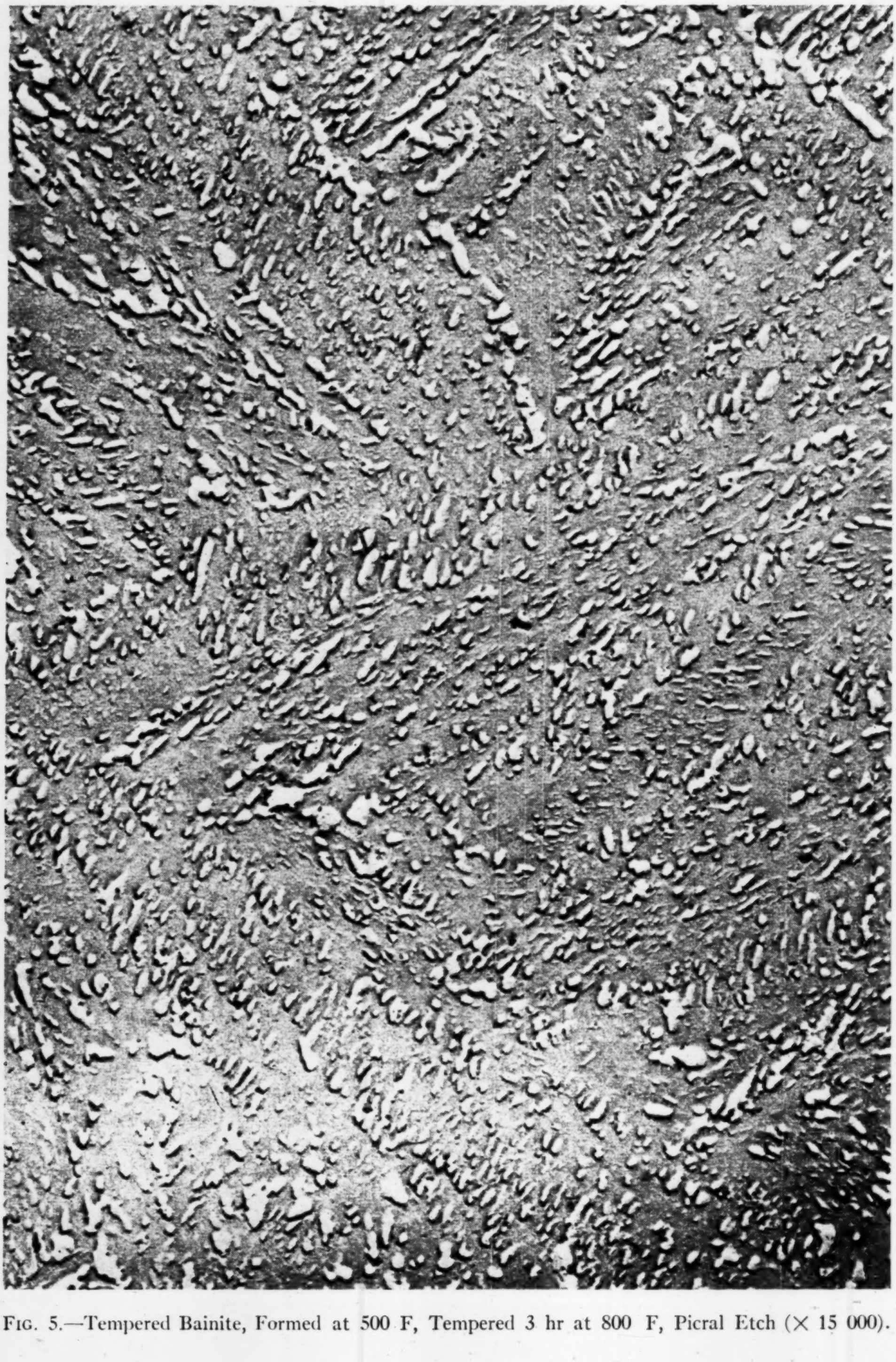

FIG. 5.—Tempered Bainite, Formed at 500 F, Tempered 3 hr at 800 F, Picral Etch (× 15 000).

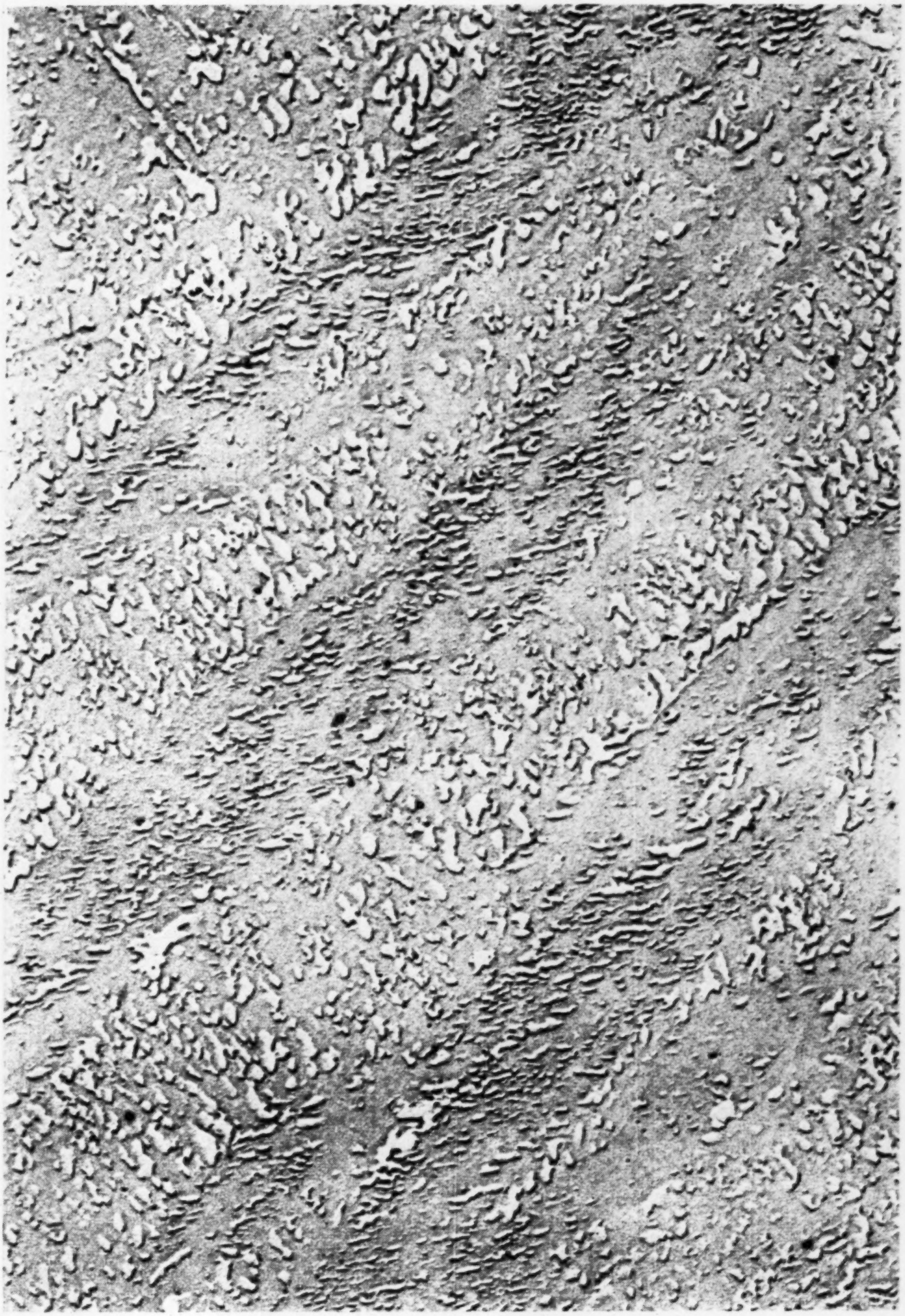

FIG. 6.—Tempered Bainite, Formed at 500 F, Tempered 6 hr at 800 F, Picral Etch (× 15 000).

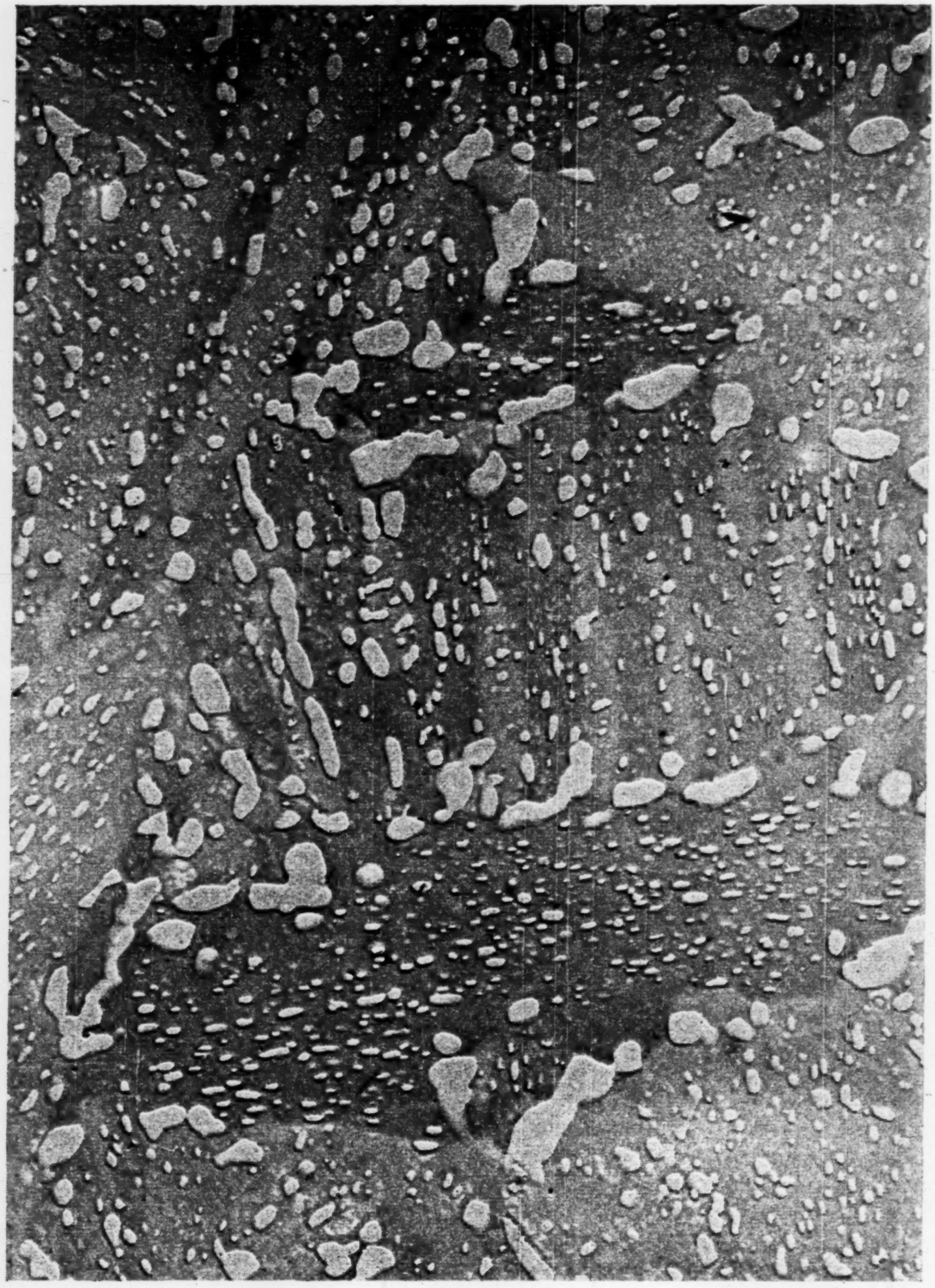

FIG. 7.—Tempered Bainite, Formed at 500 F, Tempered 1 hr at 1100 F, Picral Etch (× 15 000).

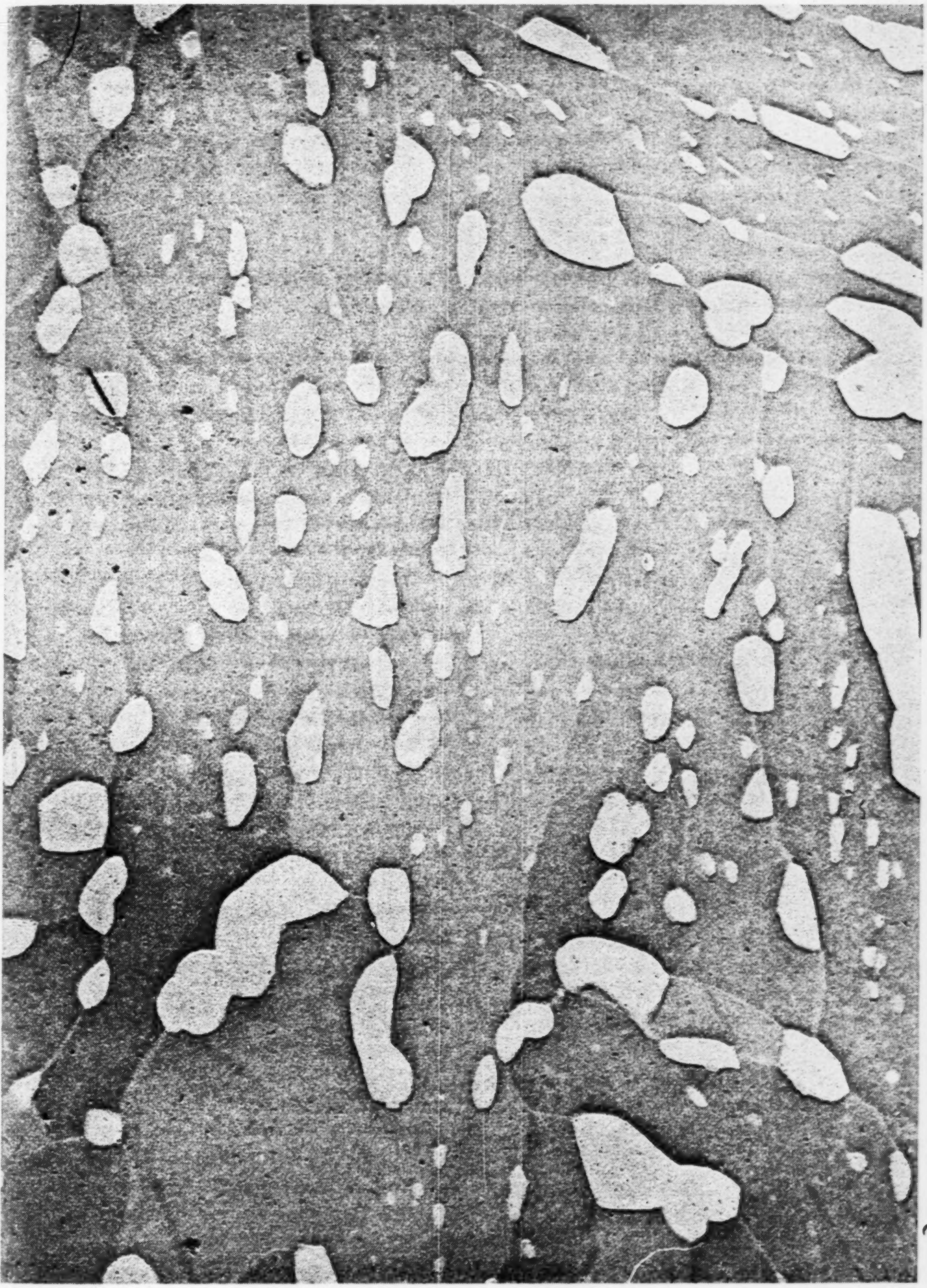

FIG. 8.—Tempered Bainite, Formed at 500 F, Tempered 12 hr at 1250 F, Picral Etch (× 15 000).

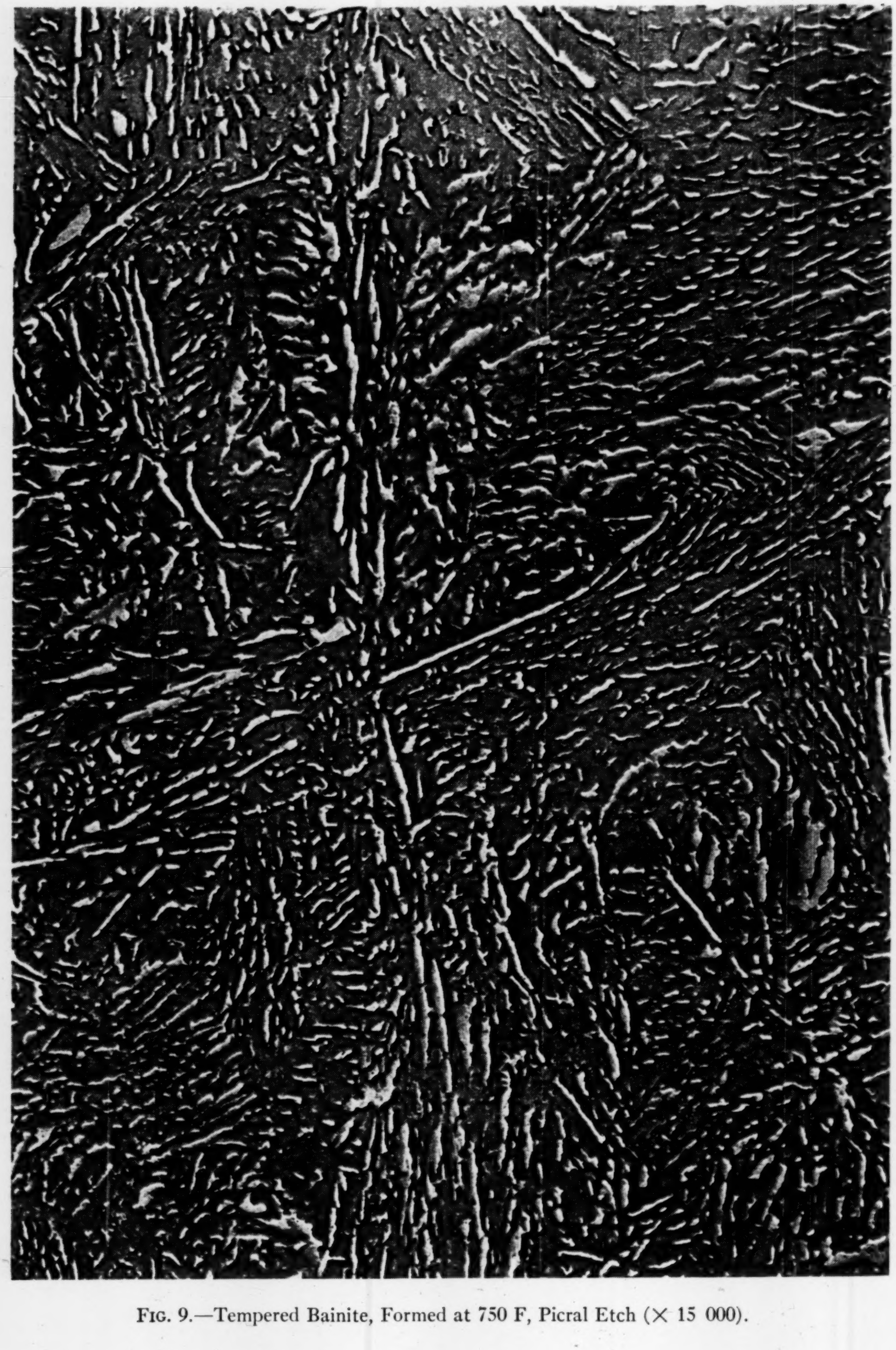

FIG. 9.—Tempered Bainite, Formed at 750 F, Picral Etch (× 15 000).

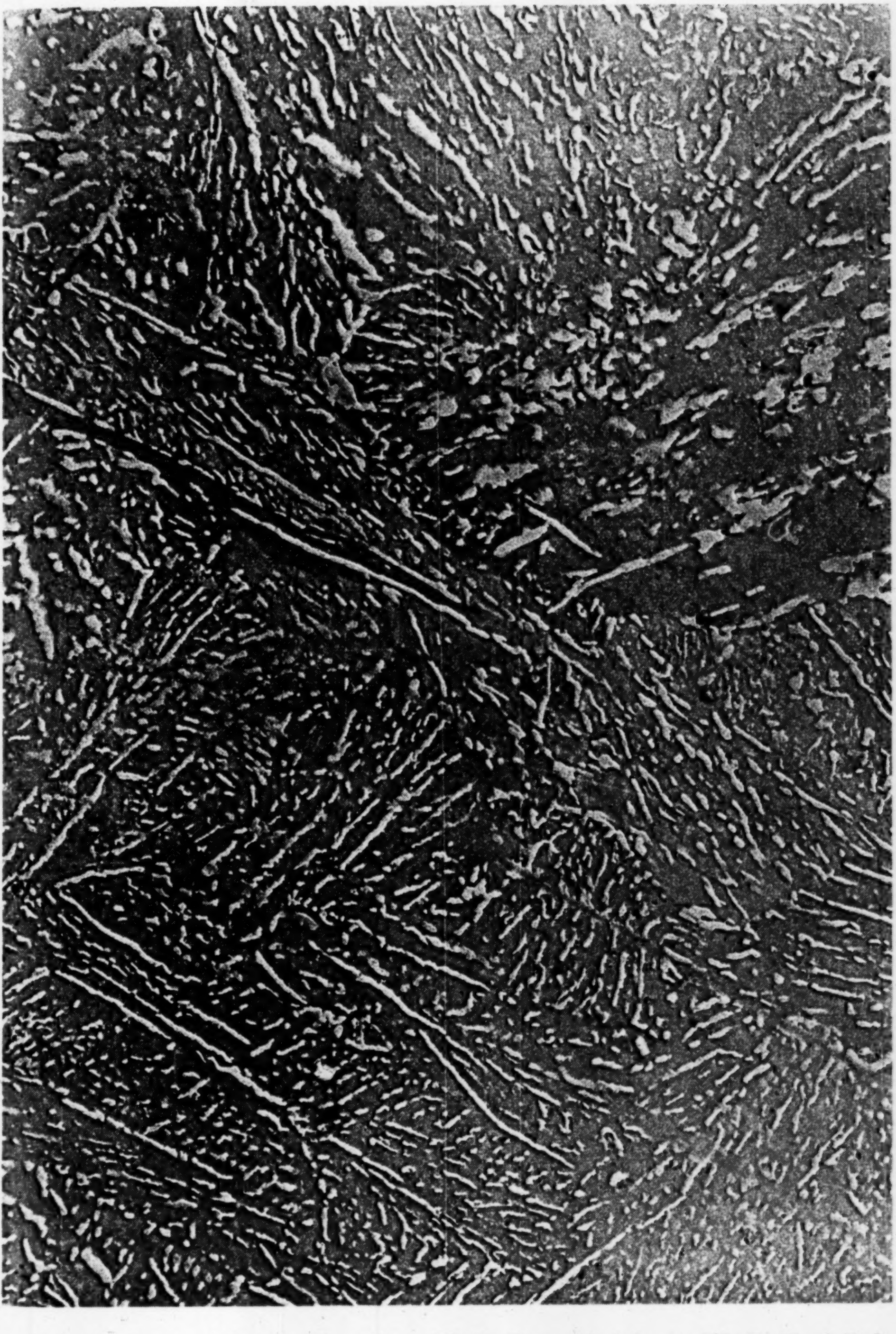

FIG. 10.—Tempered Bainite, Formed at 750 F, Tempered 1 hr at 800 F, Picral Etch (× 15 000).

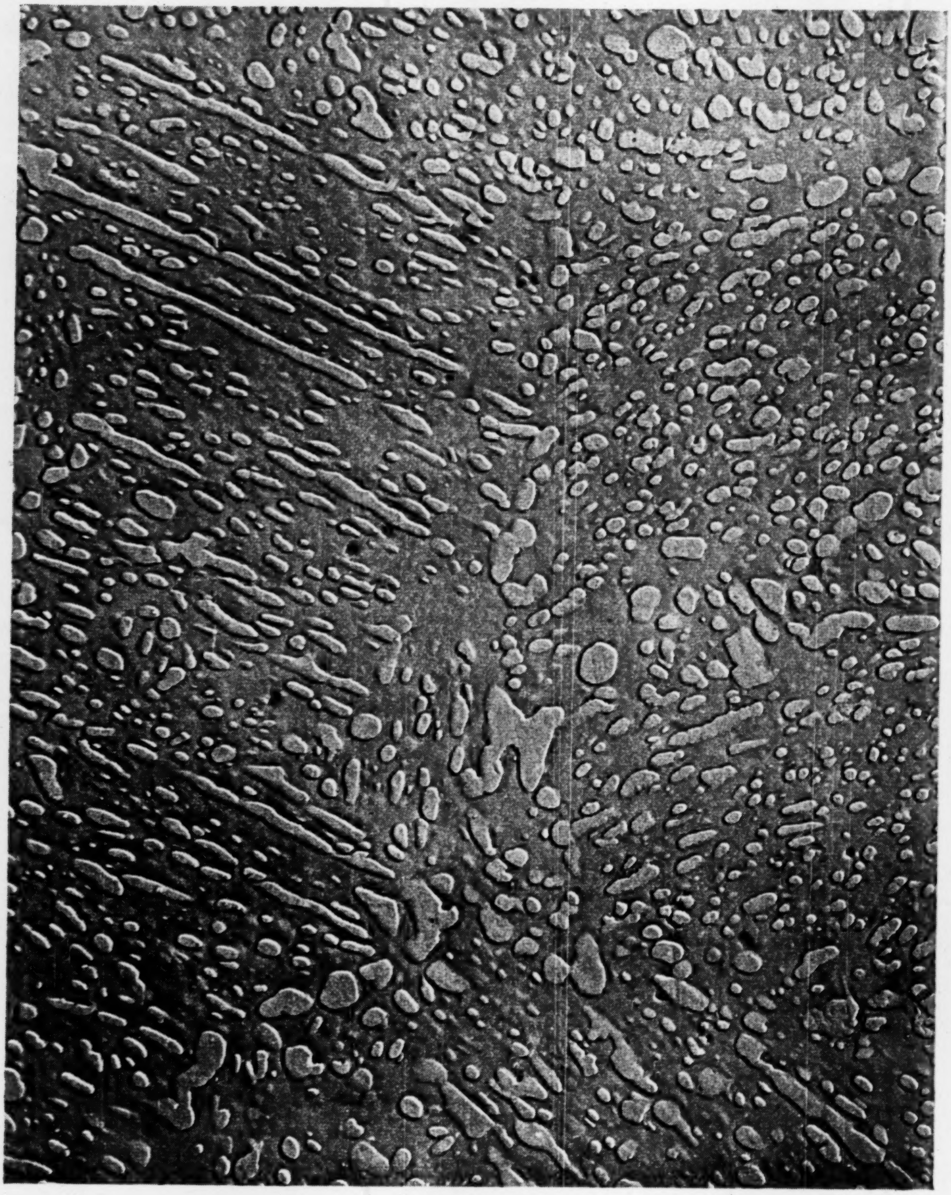

FIG. 11.—Tempered Bainite, Formed at 750 F, Tempered 1 hr at 1100 F, Picral Etch (× 15 000).

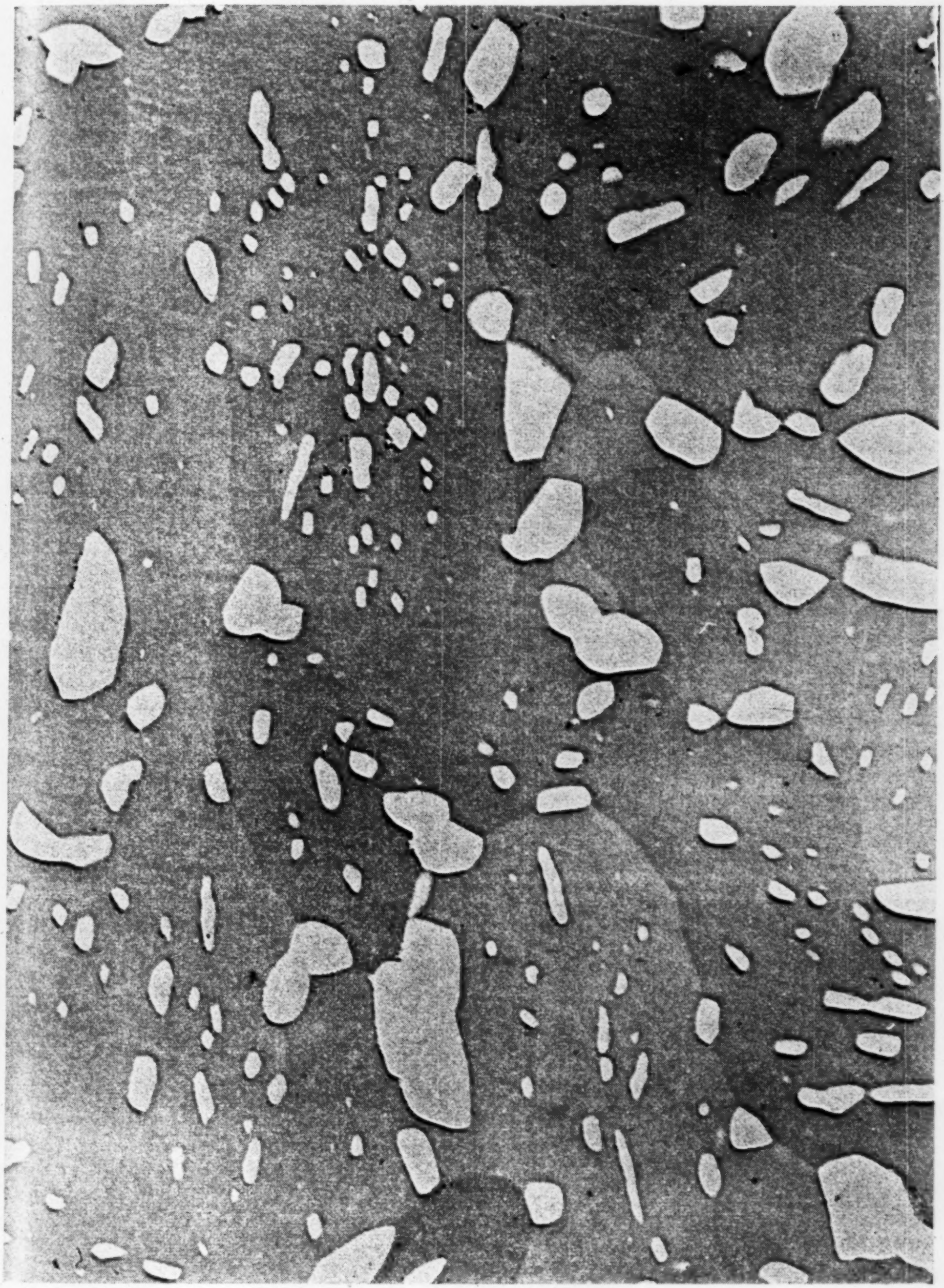

FIG. 12.—Tempered Bainite, Formed at 750 F, Tempered 12 hr at 1250 F, Picral Etch (× 15 000).

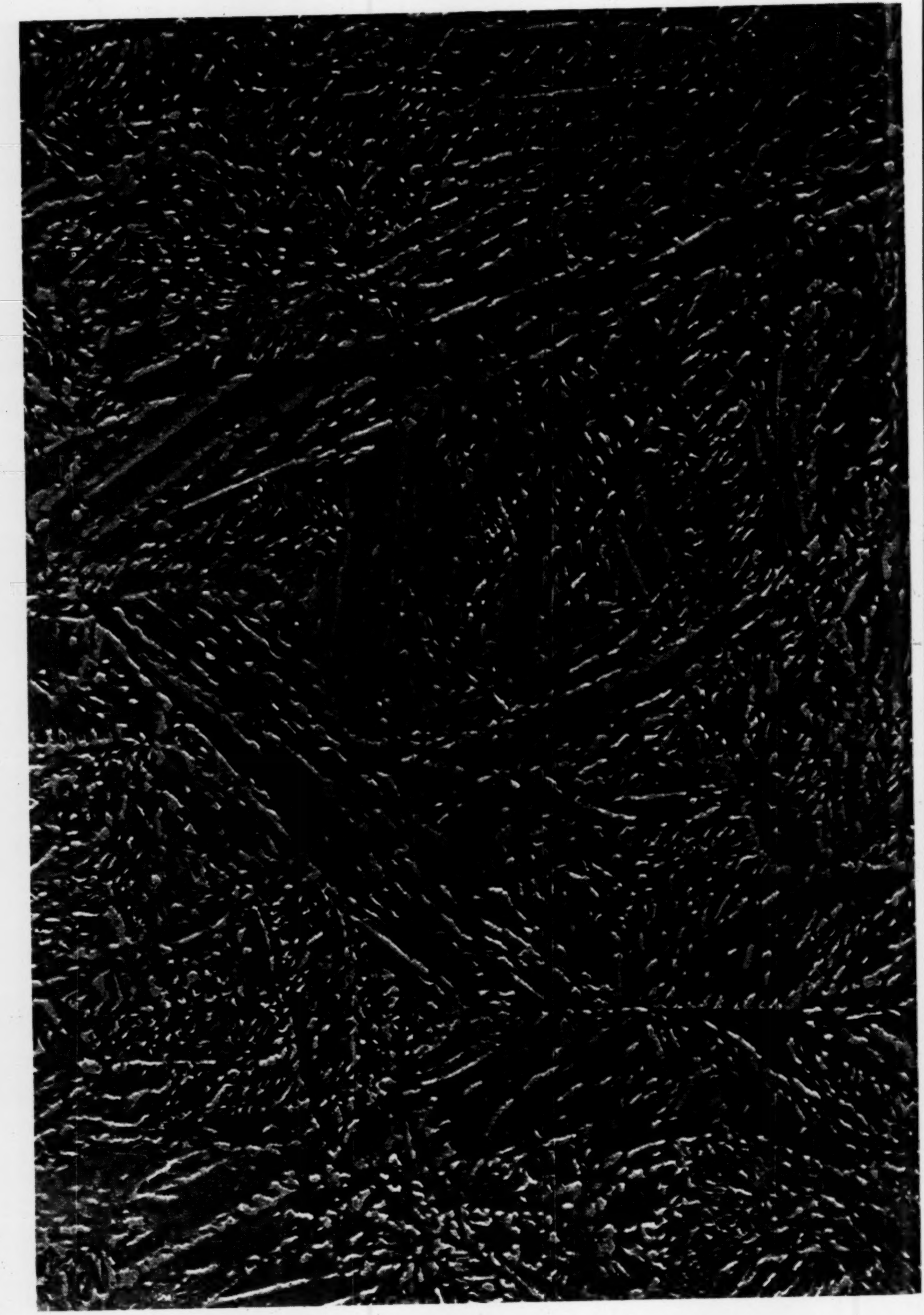

FIG. 13.—Martensite Tempered 1 hr at 800 F, Picral Etch (× 15 000).

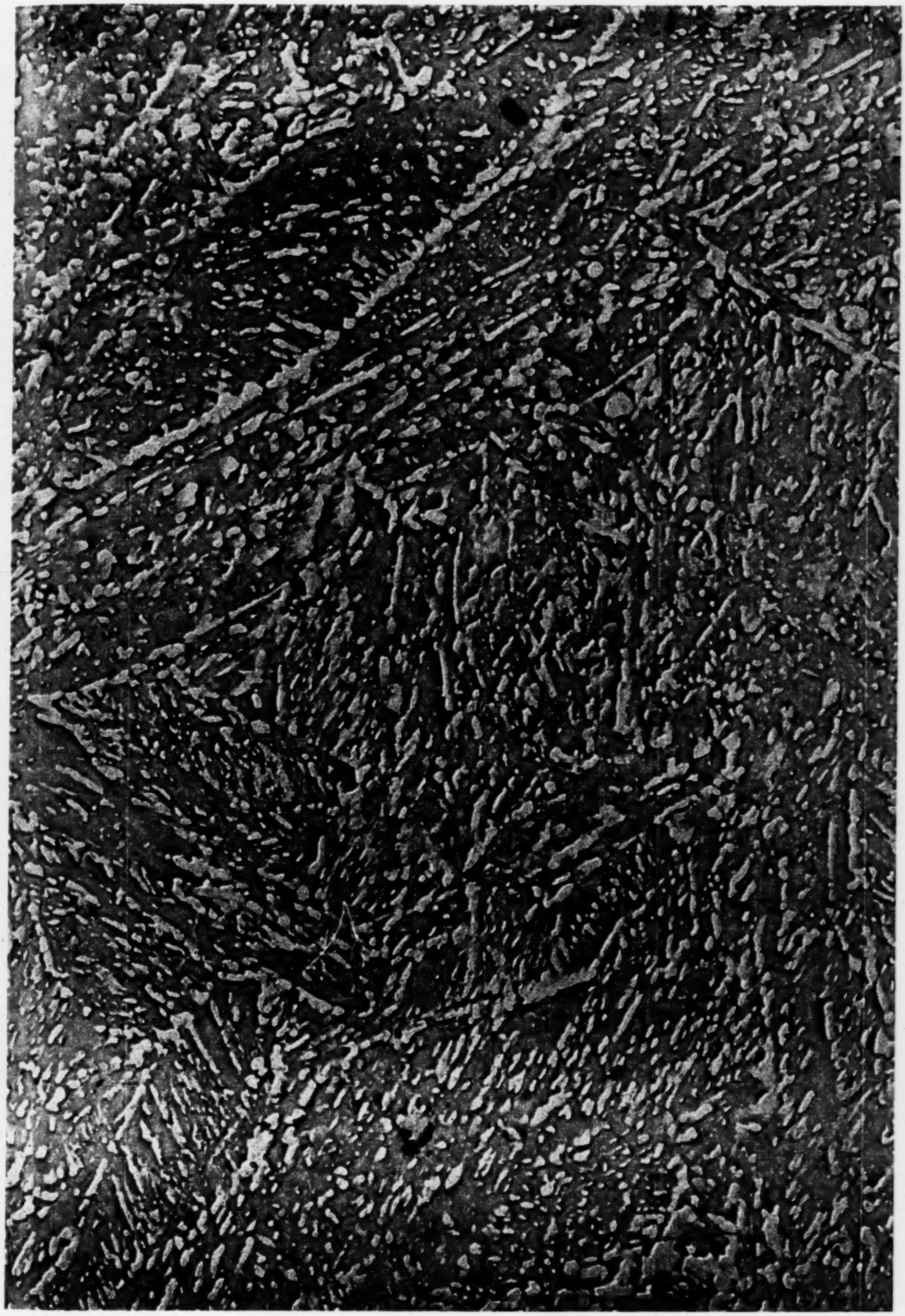

FIG. 14.—Martensite Tempered 6 hr at 800 F, Picral Etch (× 15 000).

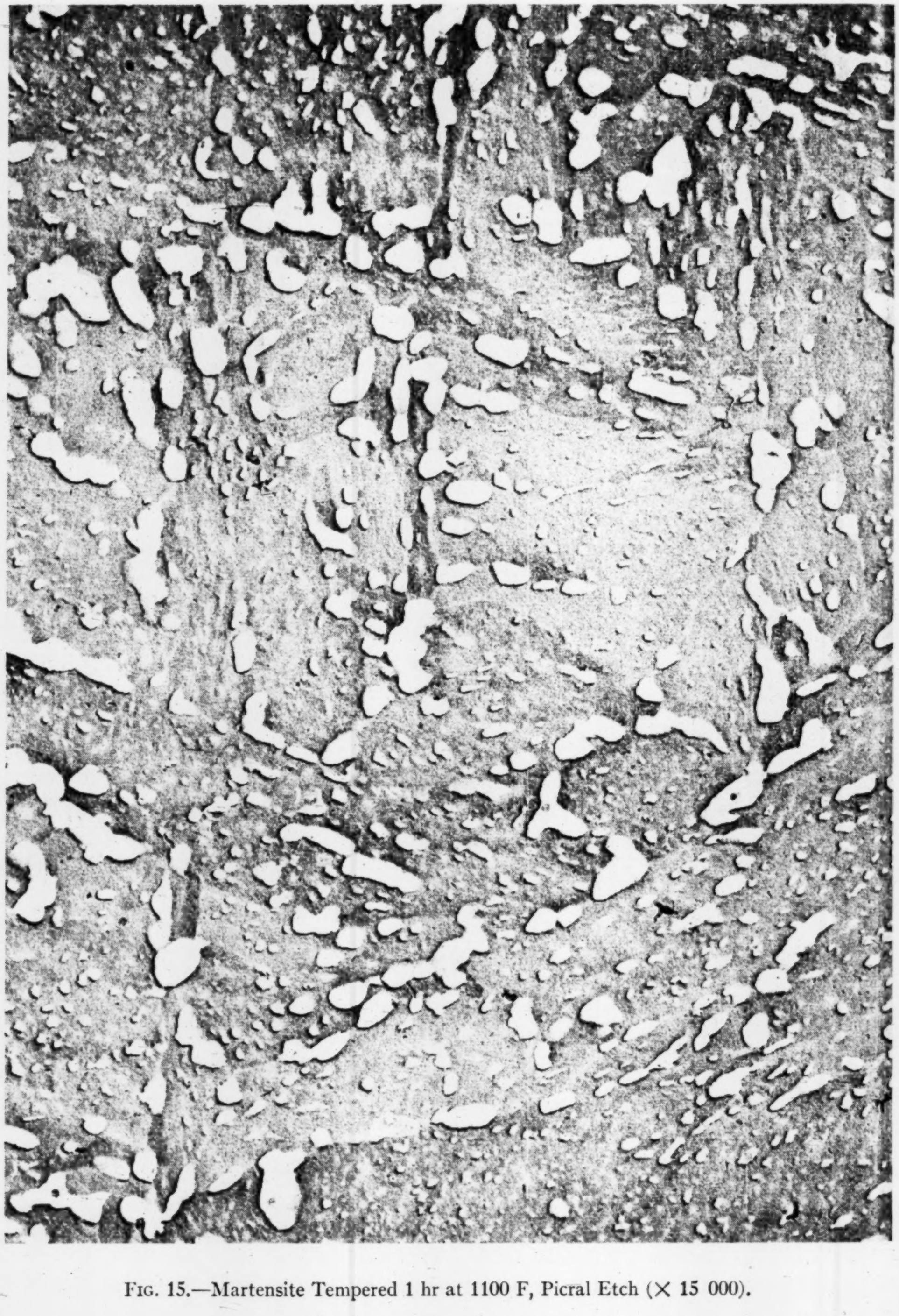

FIG. 15.—Martensite Tempered 1 hr at 1100 F, Picral Etch (× 15 000).

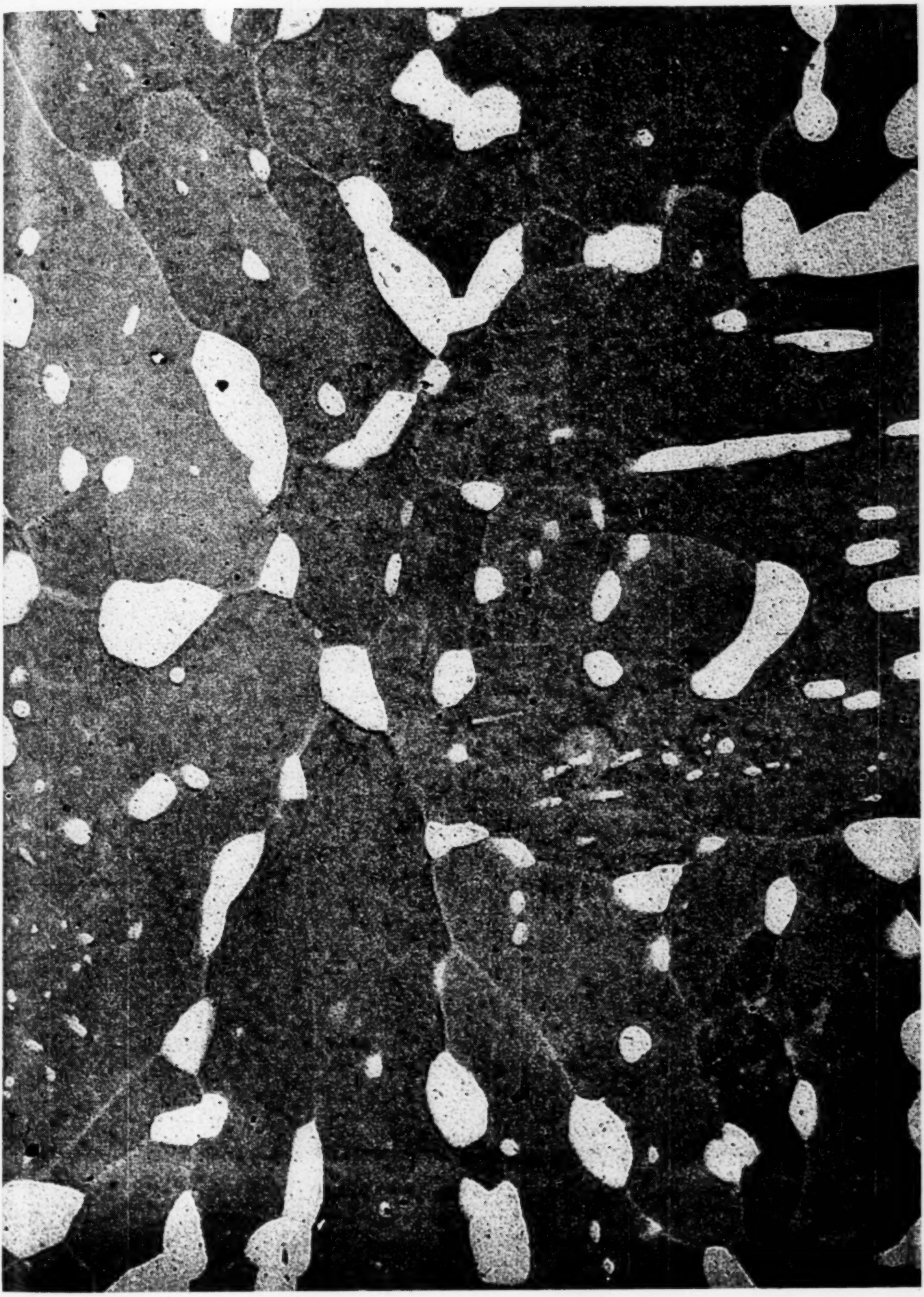

FIG. 16.—Martensite Tempered 12 hr at 1250 F, Picral Etch (× 15 000).

DISCUSSION

MR. E. E. WEISMANTEL[1] (*presented in written form*).—An interesting tabulation of the properties of the various transformation products is shown in the accompanying Table II, using the data presented in this Fourth Progress Report covering the electron microstructure of the transformation products in steel. Let us first consider the difference in hardness properties with any constant tempering temperature. For all three temperatures, there is a definite trend indicated. It seems natural that the 750 F bainite, being a more stable structure at temperature, should retain its hardness better than the lower-temperature transformation products. Within the limits of experimental error in Rockwell testing (±1), this is borne out in all cases. If this is so, then, considering differences in microstructure so obtained, there must still be some explanation for the differences in hardness results obtained on the 1250 F products. The difference between the 500 F bainite and the martensite is beyond experimental error and is explained by Subcommittee XI on the basis of grain size. This might well be the case, but it is also possible that the difference in background contrast as exhibited by these photomicrographs might be more than just differences in photographic processing. Perhaps there is something still beyond the grasp of our current resolution—perhaps even influences of domains and displacements caused by the original carbon concentrations in the sheared martensite structure—that might give rise to this type of effect. I say this because, at all other tempering temperatures, the actual resultant hardness readings are not so widely spread as at the maximum tempering temperature.

Another factor of possible significance is the microstructure presented for the lower bainite, especially for the bainite that has not been tempered. I think that it has been previously demonstrated that the upper bainitic products are basically different from martensite, being essentially the result of nucleation by precipitation of ferrite. The microstructures presented for these lower products, however, suggest to this discusser a possible type of transition structure whereby there is a tendency for a martensitic type shear. Due to energy considerations of the system, however, the stresses that originated the shear in martensite are mainly relieved by a semiplastic movement within the lattice, resulting in the compromise structure that is presented.

This last factor seems to be at least partially plausible since some investigators in the past have remarked on the similarity of properties between the lower bainites and the martensitic products.

My concluding question deals with the relative physical properties resulting from these separate products. This is an important point both from the research and the commercial aspects. There are, at present, many conflicting articles that present different viewpoints on tensile and other properties of both mixed and supposedly thoroughly transformed microstructures. Because of this confusion, one feels that perhaps some of the microstructures microscopically verified to be of one product were not actually so, and that other factors associated with mixed microstructures were predominating. This then is another field that must be investigated to avoid the confusion and misinformation that may arise out of individual studies.

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[1] Senior Metallurgist, Piasecki Helicopter Corp., Morton, Pa.

TABLE II.—VARIATION OF RETAINED HARDNESS PROPERTIES OF FERROUS TRANSFORMATION PRODUCTS AS AFFECTED BY TEMPERING TEMPERATURE.

Tempering Temperature	Martensite		500 F Bainite		750 F Bainite	
	Hardness, R_c	Original Hardness Retained, per cent	Hardness, R_c	Original Hardness Retained, per cent	Hardness, R_c	Original Hardness Retained, per cent
1250 F	20.1[a]	31[a]	16.5	29	18.5	42
1100 F	32.6	50[a]	34.2	60	33.2	76
800 F:						
1 hr	44.1	68[a]	47.7	83	42.5	97
3 hr			44.5	78		
6 hr	45.0	69[a]	43.5	76		
As formed	65.1[a]		57.4		43.8	

[a] Corrected figures by W. L. Grube.

TABLE III.—RETAINED HARDNESS OF FERROUS TRANSFORMATION PRODUCTS AS AFFECTED BY TEMPERING TEMPERATURE.

Tempering Temperature	Time, hr	500 F Bainite		750 F Bainite		Martensite	
		Hardness, R_c	Original Hardness Retained, per cent	Hardness, R_c	Original Hardness Retained, per cent	Hardness, R_c	Original Hardness Retained, per cent
As formed		57.4		43.8		65.1	
800 F	1	47.7	83	42.5	97	44.1	68
800 F	3	44.5	78				
800 F	6	43.5	76			45.0	69
1100 F	1	34.2	60	33.2	76	32.6	50
1250 F	12	16.5	29	18.5	42	20.1	31

I have attempted to review this article with the respect that is due work of this significance. The importance of and necessity for the continuation of this type of cooperative program should be emphasized.

MR. W. L. GRUBE (*author's closure*).—Mr. Weismantel's observations concerning the percentage hardness retained upon tempering the three microstructures examined are interesting. However, it does not appear that the greater percentage of the original hardness retained by the 750 F bainite is a significant factor in this case. It is true that the percentage hardness retained in the tempered 750 F bainite is invariably greater than that in the other structures, but not to be overlooked is the fact that 750 F bainite is considerably softer than the others in the untempered state. As shown on the accompanying Table III, hardness retained after tempering appears to be chiefly a function of tempering temperature rather than the original microstructure, since the hardness values of the three microstructures do not bear the same relationship to each other from one tempering temperature to another.

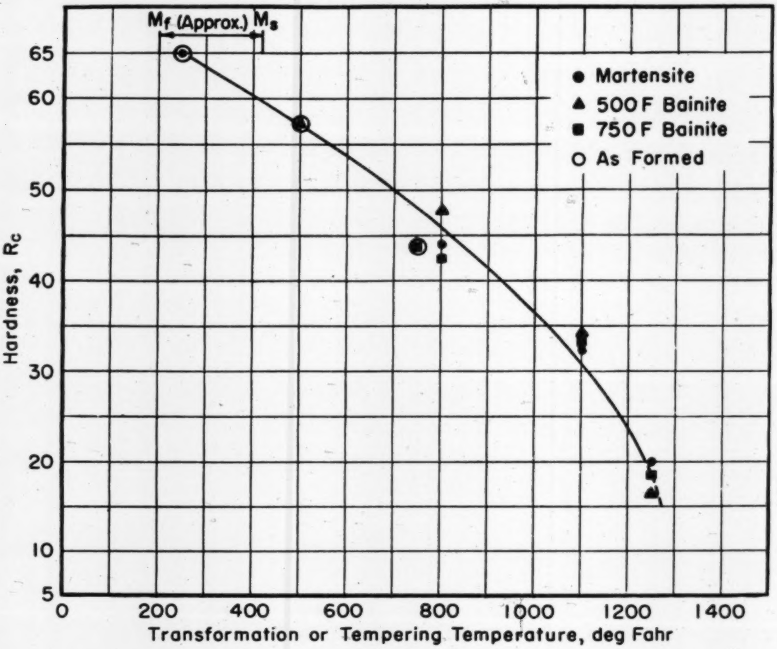

FIG. 17.

The spread in hardness between the spheroidized martensite and the spheroidized 500 F bainite, mentioned by Mr. Weismantel, is not too significant for two reasons. First, as shown by the plot of hardness *versus* tempering temperature (the accompanying Fig. 17), these values fall at a point on the curve where the slope is quite steep. Hence, very small differences in temperature, such as may exist in different locations in the furnace, may result in measurable differences in hardness. Second, and perhaps more significant, is the fact that the Rockwell C scale is not considered accurate below R_c 20, and hence the spread between the two values is probably no greater than the limits of experimental reliability.

Regarding Mr. Weismantel's proposed mechanism for the formation of lower bainite, the results presented in this report do not provide supporting evidence.

Mr. Weismantel's concluding point is well taken. When attempting to correlate mechanical properties with microstructure, the importance of working with microstructures whose identity has been carefully established cannot be overemphasized.

REPORT OF COMMITTEE E-5

ON

FIRE TESTS OF MATERIALS AND CONSTRUCTIONS*

Committee E-5 on Fire Tests of Materials and Constructions held two meetings during the year: one in Atlantic City, N. J., on July 2, 1953, and the other in Washington, D. C., on February 5, 1954.

The committee consists of 54 members, of whom 26 are classified as producers, 7 as consumers, and 21 as general interest members, with 4 consulting members.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, A. L. Brown.
Vice-Chairman, W. J. Krefeld.
Secretary, R. C. Corson.

REVISION OF STANDARD, IMMEDIATE ADOPTION

The committee recommends that the following revision of the Standard Methods of Fire Tests of Building Construction and Materials (**E 119 - 53**)[1] be approved for reference to letter ballot of the Society for immediate adoption and accordingly asks for the necessary nine-tenths affirmative vote at the Annual Meeting in order that this revision may be referred to letter ballot of the Society:

Introduction.—Delete the last paragraph.

ADOPTION OF TENTATIVE REVISION AS STANDARD

The committee recommends that the tentative revisions of the Standard Methods of Fire Tests of Building Construction and Materials (**E 119 - 53**)[1] relating to Sections 9 and 26, issued June, 1953,[1] be approved for reference to letter ballot of the Society for adoption as standard.

TENTATIVE REVISION OF STANDARD

This committee recommends the following tentative revisions of Standard Methods of Fire Tests of Building Construction and Materials (**E 119 - 53**):[1]

Section 4.—Change Paragraph (*b*) to read as follows:

> "(b) Temperature readings shall be taken at not less than nine points on the surface. Five of these shall be symmetrically disposed, one to be approximately at the center of the specimen, and four at approximately the center of its quarter sections. The other four shall be located at the discretion of the testing authority to obtain representative information on the performance of the construction under test. None of the thermocouples shall be nearer than one and one-half times the thickness of the construction, or nearer than 12 in. to the edges, and none of them shall be located opposite or on top of beams, girders, pilasters, or other structural members if temperatures at such points will obviously be lower than at more representative locations."

Section 5.—Add the following at the end of Paragraph (*a*):

> "Reports shall include observations of significant details of the behavior of the material

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13–18, 1954.

[1] 1953 Supplement to Book of ASTM Standards, Part 4.

or construction during the test and after the furnace fire is cut off, including information on deformation, spalling, cracking, burning of the specimen or its component parts, continuance of flaming, and production of smoke."

TENTATIVES CONTINUED WITHOUT REVISION

The committee recommends that the following tentative and tentative revision be continued as tentative without revision:

Tentative Method of:

Fire Hazard Classification of Building Materials (E 84 - 50 T).

Tentative Revision of Standard Methods of:

Fire Tests of Building Construction and Materials (E 119 - 53), relating to Section 6.

EDITORIAL CHANGE

The committee recommends the following editorial change in the Standard Methods of Fire Tests of Building Construction and Materials (E 119 - 53):

Section 25.—In the first line, add the word "test" after the word "endurance" and delete the immediately following phrase "and fire and hose stream tests." This conforms with the deletion of Section 26(*b*).

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[2]

ACTIVITIES OF SUBCOMMITTEES

A draft of a fire test method using small size specimens, which was prepared by a special task group at the suggestion of ASTM Committee E-6 on Methods of Testing Building Construction and proposed for inclusion as an appendix to Standard Methods E 119, is to be given further consideration by the special group prior to submission of Subcommittee I for action.

Subcommittee I on Fire Tests of Materials and Construction (G. N. Thompson, chairman).—A special task group studied the requirements of Section 10 of E 119 pertaining to conditioning of specimens. The subcommittee, after receiving the report, decided unanimously that no changes should be made.

A special task group is studying the possibility of expanding Sections 27 to 30, inclusive of E 119, entitled "Alternate Test of Protection for Solid Structural Steel Beams and Girders," to include steel joists and similar open web members.

Subcommittee III on Fire Tests of Wall Openings Assemblies (H. D. Foster, chairman).—A revised draft of the Standard Methods of Fire Tests of Door Assemblies (E 152 - 41) to replace the present standard has been submitted to the members for study and discussion at a future meeting.

Subcommittee IV on Fire Tests of Acoustical and Similar Finishes.—A report on the status of the small tunnel project, now under way at the Forest Products Laboratories, indicates that funds from industry were solicited to conduct further tests to perfect draft conditions and methods of observing results. Industry responded generously and the investigation is being pursued. The present technical task group has been enlarged to include members of industry who have contributed funds for the research and others vitally interested, so as to afford them the opportunity to be currently informed on the progress work and to make suggestions or comments regarding the conducting of tests.

Subcommittee V on Nomenclature and Definitions (J. R. Shank, chairman).—A tentative method of test for use in defining the term "noncombustible" as applied to building materials has been prepared and submitted to Committee E-5 members for review prior to discussion at a future meeting.

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[2] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

Subcommittee VIII on Fire Tests of Roof Coverings (A. J. Steiner, chairman).—A draft of a proposed method for establishing the fire hazard of roof coverings has been discussed at length but no action taken pending the review of a similar draft being prepared by a technical committee of the Asphalt Roofing Industry Bureau which will be available in the near future. Both drafts will receive further consideration by the subcommittee before being submitted to the committee.

This report has been submitted to letter ballot of the committee, which consists of 54 voting members; 45 members returned their ballots, of whom 44 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

A. L. Brown,
Chairman.

R. C. Corson,
Secretary.

REPORT OF COMMITTEE E-6

ON

METHODS OF TESTING BUILDING CONSTRUCTIONS*

Committee E-6 on Methods of Testing Building Constructions held one meeting during the year: on June 30, 1953, at Atlantic City, N. J., during the Annual Meeting of the Society.

The committee consists of 60 members of whom 51 are voting members; the membership is not classified. The committee regrets to report the death on March 16, 1953, of F. H. Alcott, a representative of the National Lumber Manufacturers Assn.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, R. F. Legget.
Vice-Chairman, Harold Perrine.
Secretary, R. F. Biggs.

ADOPTION OF TENTATIVE AS STANDARD

The committee recommends that the Tentative Methods of Conducting Strength Tests of Panels for Building Construction (**E 72 – 51 T**)[1] be approved for reference to letter ballot of the Society for adoption as standard without change.

The revision in the methods in 1951 was made to incorporate additional testing procedures and to include information on recent developments in testing equipment and measuring apparatus. The method has had considerable study and use since that time, and it appears desirable to have the methods adopted as standard.

TENTATIVE CONTINUED WITHOUT REVISION

The committee recommends that the Tentative Recommended Practice for Laboratory Measurement of Airbourne-Sound Transmission Loss of Building Floors and Walls (**E 90 – 50T**)[1] be continued as tentative without revision. It is believed that this procedure needs further review and use. The procedure is being used as the basis for discussion by an ASA group, and it appears that it should not be established as a full standard until the ASA group has finished its work.

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[2]

ACTIVITIES OF SUBCOMMITTEES

The members of Committee E-6, through the various subcommittees, have continued in their studies to develop and improve present methods of testing building constructions. It is hoped that this objective will be furthered by the Symposium on Methods of Testing Building Constructions[3] that will be presented at the 1954 Annual Meeting of the Society, under the sponsorship of Committee E-6. In the light building construction field, wherein test methods for evaluating the strength properties of wall panels have been developed, liaison has been established with committees who wish to use such methods for evaluating sheet materials, in an effort to provide a standardized testing procedure that will fulfill both objectives. The latest draft of a proposed method of test of strength and stiffness of prefabricated floor and roof constructions is being reviewed. Problems of heat and water vapor transmission through building constructions are being studied first by evaluation of these properties for materials through liaison work with other committees. Interest in small-scale fire test procedures is continuing, and it is hoped the procedure developed by Committee E-6 will soon be established as a tentative standard.

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13–18, 1954.

[1] 1952 Book of ASTM Standards, Part 4.

[2] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

[3] Issued as separate publication *ASTM STP No. 166*.

This report has been submitted to letter ballot of the committee, which consists of 51 voting members; 36 members returned their ballots, of whom 34 have voted affirmatively and 2 negatively.

Respectfully submitted on behalf of the committee,

J. A. LISKA,
Chairman.

R. A. BIGGS,
Secretary.

REPORT OF COMMITTEE E-9
ON
FATIGUE*

At the February, 1954, meeting, steps were taken to begin organization of Subcommittee V on Aircraft Structural Problems. The purpose of the activity is to attempt to present aircraft structural problems in such a form that the experience of Committee E-9, representing laboratories of government, university, and industrial types, can be drawn upon. Problems of spectrum loading, stress concentration effect, size effect, statistical interpretation, and biaxial stress are of the general kind now being considered by groups having widely different interests. It is not intended that the details of aircraft design, as such, be part of the subcommittee's activity; cooperation with industry committees will be maintained through certain members common to both groups. Subcommittee V will be under the chairmanship of P. Kuhn of the National Advisory Committee for Aeronautics. Selection of personnel is now under way.

A number of changes have occurred in the subcommittees during the past year. T. J. Dolan has been appointed chairman of Subcommittee I (Research) replacing H. F. Moore who wished to be relieved of this responsibility. H. J. Grover has been appointed chairman of Subcommittee III (Survey), replacing T. J. Dolan. The personnel of all subcommittees has been reviewed and a considerable number of new members have been added.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, R. E. Peterson.

Secretary, O. J. Horger.

Subcommittee I on Research (T. J. Dolan, chairman).—A questionnaire has been sent to determine the chief interests and future activity of the subcommittee. Subjects discussed at the spring meeting were: theories of failure and effect of anisotropy, effect of biaxial stress, and effect of temperature in the blue brittle range.

Subcommittee II on Papers (W. T. Lankford, chairman).—The following papers are scheduled for the 1954 Annual Meeting:[1]

"Softening of Certain Cold-Worked Metals Under the Action of Fatigue Loads," by N. N. Polakowski, Armzen Co., and A. Palchoudhuri, The Small Tools Manufacturing Co. of India, Ltd.

"Dynamic Creep and Rupture Properties of an Aluminum Alloy Under Axial Static and Fatigue Stress," by F. W. DeMoney and B. J Lazan, University of Minnesota.

"The Influence of Test Temperature and Grain Size on the Fatigue Notch Sensitivity of Refractaloy-26," by P. R. Toolin, Westinghouse Electric Corp.

"Experiments in Fatigue Under Ranges of Stress in Torsion and Axial Load from Tension to Extreme Compression," by W. N. Findley, University of Illinois.

"Fatigue Strength of 14S-T4 Aluminum Alloy Subjected to Biaxial Stresses," by Robert W. Bundy, E. I. du Pont de Nemours & Co., Inc., and J. Marin, Pennsylvania State University.

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13–18, 1954.

[1] These papers appear in this volume except as noted

"Investigations Concerning the Fatigue of Aircraft Structures," by Robert A. Carl and Thomas J. Wegeng, Bureau of Aeronautics.

"Fatigue Tests Under Progressive Stress, a Theory of Fatigue of Metals and a Quick Method for Determining the Fatigue Limit," by Nobusuke Enomoto, Railway Technical Laboratory, Japan.[2]

"A Simplified Statistical Procedure for Obtaining Design-Level Fatigue Curves," by E. H. Schuette, The Dow Chemical Co.

"An Experimental Study of the Influence of Fluctuating Stress Amplitude on Fatigue Life of 75S-T6 Aluminum," by H. T. Corten, G. M. Sinclair, and T. J. Dolan, University of Illinois.

"Metallographic Aspects of Fatigue Behavior of Aluminum," by M. S. Hunter and W. G. Fricke, Jr., Aluminum Company of America.

"A Failure Criterion for Multi-Axial Fatigue Stresses," by F. B. Stulen and H. N. Cummings, Curtiss-Wright Corp.

"An Appraisal of the Prot Method of Fatigue Testing," by H. T. Corten, Todor Dimoff, and T. J. Dolan, University of Illinois.

A paper entitled "A Fatigue Testing Machine for Range of Stress," by J. P. Romualdi, Chiao-Lin Chang, and Charles F. Peck, Jr., is scheduled for BULLETIN publication.[3]

Subcommittee III on Survey (H. J. Grover, chairman).—There has now been published by the Society the 1952 References on Fatigue (*ASTM STP No. 9-D*) which consists of 48 pages with references arranged for clipping to card size.

Subcommittee IV on Large Machines and Test Correlation (J. M. Lessells, chairman).—A discussion was held wherein the results of tests made in England were analyzed and a general presentation on size effect written at Battelle Memorial Inst. was reviewed. A symposium on this subject is being planned for next year.

This report has been submitted to letter ballot of the committee, which consists of 44 members; 37 members returned their ballots, of whom 36 have voted affirmatively and 1 negatively.

Respectfully submitted on behalf of the committee,

R. E. PETERSON,
Chairman.

O. J. HORGER,
Secretary.

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[2] To be published in *Proceedings*, Am. Soc. Testing Mats., Vol 55 (1955).

[3] ASTM BULLETIN, No. 200, September, 1954, p. 39 (TP 165).

REPORT OF COMMITTEE E-10

ON

RADIOACTIVE ISOTOPES*

The organization of Committee E-10 on Radioisotopes was prompted by the increasing uses of such materials in industry. The activity of the first two years was devoted to securing a broad representative membership and working out the scope and general program of activities.

A Symposium on Radioactivity—An Introduction was held at the Annual Meeting in June, 1953, and the interest in this meeting prompted the committee to arrange for publication of this material.[1]

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, G. D. Calkins.

Vice-Chairman, C. E. Crompton.

Secretary, C. E. Weber.

During 1954 Committee E-10 organized six technical subcommittees as follows:

Subcommittee 1 on Isotopic Applications and Methods (E. B. Ashcraft, chairman).

Subcommittee 2 on Health and Safety (R. C. Stratton, chairman).

Subcommittee 3 on Radiation Standards and Counting Techniques (G. G. Manov, chairman).

Subcommittee 4 on Radioisotope Gages (G. D. Calkins, chairman).

Subcommittee 5 on Tracer Methodology (J. R. White, chairman).

Subcommittee 6 on Analytical Methods (J. L. Kurnz, chairman).

Other ASTM committees desiring representation on Committee E-10 are advised to contact the secretary of the committee.

Respectfully submitted on behalf of the committee,

Don M. McCutcheon,
Chairman.

C. E. Weber,
Secretary.

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13–18, 1954.

[1] Issued as separate publication *ASTM STP No. 159.*

REPORT OF COMMITTEE E-11

ON

QUALITY CONTROL OF MATERIALS*

Committee E-11 on Quality Control of Materials, through amendment of its regulations, has made provision for associate membership. This is limited to one representative from each ASTM technical committee. The function of these members is to transmit to Committee E-11 problems on the application of statistical methods to standardization and to relay back to the technical committees information on the activities of Committee E-11.

A Subcommittee on ASTM Problems has been appointed under the chairmanship of C. A. Bicking. Associate members of Committee E-11 are members of this subcommittee. Its function is to review and make recommendations on problems of general interest involving the application of quality control methods to ASTM standards.

Committee E-11 sponsored a Symposium on the Design of Experiments, at ASTM Committee Week.

A Task Group on Design of Experiments, under the chairmanship of W. J. Youden, has been appointed. Its purpose is to prepare material presenting the objectives of experimental design and a discussion of the basic principles and devices employed in design.

Other active task groups include:

Sampling Plans (O. P. Beckwith, chairman),
Planning Interlaboratory Test Programs (Grant Wernimont, chairman),
Number of Tests for a Desired Precision of an Average (A. G. Scroggie, chairman),
Bulk Sampling (W. E. Deming, chairman),
Smoothing Empirical Data (J. H. Curtiss, chairman), and
Precision and Accuracy (L. E. Simon, chairman).

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, H. F. Dodge.
Vice-Chairman, C. A. Bicking.
Secretary, O. P. Beckwith.

This report has been submitted to letter ballot of the committee, which consists of 21 members; 18 members returned their ballots, of whom 17 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

H. F. Dodge,
Chairman.

O. P. Beckwith,
Secretary.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee E-11 presented to the Society through the Administrative Committee on Standards the Tentative Recommended Practice for the Probability Sampling of Materials. The recommended practice was accepted by the Standards Committee on September 28, 1954, and it appears in the 1954 Supplement to Book of ASTM Standards, Parts 3, 4, and 6, bearing the designation E 105 – 54 T.

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13–18, 1954.

REPORT OF COMMITTEE E-13

ON

ABSORPTION SPECTROSCOPY*

Committee E-13 on Absorption Spectroscopy held two meetings during this year: one in Chicago on September 11, 1953, the other in Pittsburgh on March 6, 1954. The next committee meeting will he held in conjunction with the Pittsburgh Conference on Analytical Chemistry and Applied Spectroscopy in March, 1955. Several of the subcommittees plan to meet in Columbus, Ohio, in June.

The election of officers resulted in the selection of the following:

Chairman, E. J. Rosenbaum.

Vice-Chairman, N. R. Trenner.

Secretary, R. F. Robey.

Members-at-Large of Executive Committee, L. E. Kuentzel and M. G. Mellon.

One of the major developments during this year was the transfer to ASTM of responsibility for the maintenance and distribution of the IBM Punch Card Index System for Infrared Spectra which was developed at the Wyandotte Chemical Corp. by L. E. Kuentzel.

The committee accepted codes proposed by Mr. Kuentzel for ultraviolet and visible spectra. The empirical formula index card developed by Mr. Kuentzel and D. H. Anderson was adopted as an ASTM form. The abstracting program for infrared spectra was active, and plans were made to start an ultraviolet abstracting program.

Progress was reported by both the Nomenclature and Apparatus Specifications Subcommittees. The Methods Subcommittee is dormant at present, but plans were made to direct its activity toward cooperation with product committees.

Respectfully submitted on behalf of the committee,

E. J. Rosenbaum,
Chairman.

W. S. Young,
Secretary.

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13–18, 1954.

TECHNICAL PAPERS

With Discussions

EDGAR MARBURG LECTURE

THE PURPOSE of the Edgar Marburg Lecture is to have described at the Annual Meetings of the American Society for Testing Materials, by leaders in their respective fields, outstanding developments in the promotion of knowledge of engineering materials. Established as a means of emphasizing the importance of promoting knowledge of materials, the Lecture honors and perpetuates the memory of Edgar Marburg, first Secretary of the Society.

INTERPRETATION OF ENGINEERING DATA: SOME OBSERVATIONS[1]

TWENTY-EIGHTH EDGAR MARBURG LECTURE

BY HAROLD F. DODGE[2]

INTRODUCTION

This discussion of the interpretation of engineering data will be limited to some observations from the viewpoint of *quality engineering*. My encouragement to do this stems from an introductory observation made by Harold L. Maxwell, past-President of the American Society for Testing Materials, in his article, "Chemical Developments and Engineering Materials," published in a recent issue of the ASTM BULLETIN (**1**).[3] Mr. Maxwell said: "By the time an individual has spent 25 or 30 years in a particular line of work, he should have acquired the good judgment to limit his speaking to something he knows about from first-hand experience."

The field of quality engineering deals, among other things, with sampling and quality control techniques (**2, 3, 4, 5, 6**), with particular reference to the engineering problems of specification, production, and inspection. These problems involve at every turn the collection, analysis, and interpretation of quantitative data. Some of the thoughts I hope to leave with you are:

1. Statistical methods and statistical thinking are highly useful in the interpretation of data.
2. Most groups of engineering data can advantageously be regarded as samples.
3. In the interpretation of data, the human element in the cause system reflected by the data is usually of first importance.

Particular attention will be given to applications of some of the simpler statistical methods.

A SAMPLING EXPERIMENT

Sampling from a Bowl of Chips:

To give a preliminary idea of some of the things to be discussed, I should like first to run an experiment. I have here a bowl of 200 chips—some red and some white—which I should like to have you think of as representing a lot of 200 articles. Let us assume that this article is a precision piece part of some type of apparatus, such as a telephone transmitter or a carburetor, and further, let us assume we are interested in one particular feature—its diameter. The specification says this diameter shall be 0.755 ± 0.002 in. To determine whether an individual part conforms to the specification, we would use an appropriate gage. If the part has a diameter that fails to meet the specification, it would be considered as a "defective" part and would be represented by a red chip. And if the part has a diameter that falls within the

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[1] Presented at the Fifty-seventh Annual Meeting of the Society, June 16, 1954, Chicago, Ill.

[2] Quality Results Engineer, Bell Telephone Laboratories, Inc., New York, N. Y.

[3] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 637.

±0.002 in. limits, it is a conforming part and is represented by a white chip. Thus we have in the bowl 200 parts, a certain percentage of which are red. With respect to this one quality characteristic, diameter, we have as a measure of quality for this lot of parts some per cent defective; this percentage, for the moment, is unknown.

I am going to ask someone in the audience to act as an inspector for this lot of 200 parts. What we want him to do is to draw a sample of 10 from the lot, note the number of red chips in his sample, and from this result state what he considers to be the per cent defective in the entire lot. Since we want a fair sample, we shall ask him to stir the chips thoroughly, to avoid peeking, and to draw one chip at a time, until he has 10. (This is done. The sample of 10 shows 1 red chip and 9 white chips; the lot quality is judged to be "10 per cent defective." The sample is returned to the bowl; four other members of the audience repeat the experiment, and obtain respectively 0, 3, 1, 2 red chips.)

From these varying results, the question arises: Which of the samples is right? What we get appears to be a matter of chance.[4] In the practical case, the inspector would take his one sample from the lot, note the results of gaging the ten parts, and then take whatever action was appropriate. Here we have had several inspectors, each taking a sample. As far as we know, all of the samples were properly drawn. The results do not agree, hence one thing is clear: the sample quality (in per cent defective) is not necessarily the same as the lot quality.

This experiment, which will shortly be carried further, will indicate some of the ways in which a knowledge of the nature of chance variations may be of assistance in planning inspection and testing work, and in interpreting data obtained in the laboratory or in the manufacturing plant. The emphasis will be on sampling.

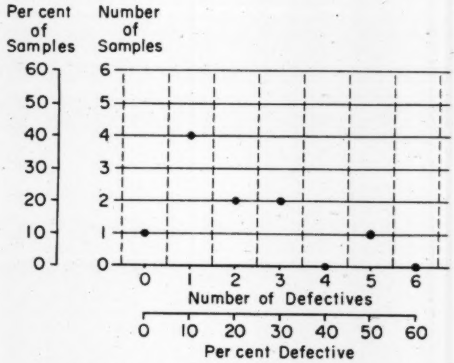

FIG. 1.—Results of Experiment—Ten Samples of 10.

TABLE I.—OBSERVED RESULTS OF EXPERIMENT.

Defectives in Sample	Samples Having This Number of Defectives
0	1
1	4
2	2
3	2
4	0
5	1
6	0

In the bowl experiment, to avoid the errors of sampling, we could of course look at all of the chips to determine what is the per cent defective. The result would be exact, *provided there were no error of count*. Again, with respect to the lot of 200 parts, we could gage all of the parts in our attempt to determine the per cent defective for diameter quality. But the measurement operation—gaging the individual part—is more prone to error than is the operation of noting whether a chip is red or white. Different operators might handle the gage differently and might not agree exactly on how many of the product units fail to meet specification. Thus, even 100 per cent inspection is not perfect, due to errors of measurement, fatigue, and other human factors.

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[4] "Aristotle (it has been said) invented Chance to cover the astonishing fact that there were certain phenomena for which he found himself wholly unable to account."—Sir Arthur Quiller-Couch, "On the Art of Writing," G. P. Putnam's Sons, New York, N. Y., p. 154 (1943).

But, as a matter of fact, sampling is often a necessity. In the first place, 100 per cent inspection may be quite impractical—when it is destructive, for example. This would be so with respect to breaking strength of bolts, blowing time of fuses, or velocity tests of ammunition. In the second place, 100 per cent inspection may be impossible—sampling alone is possible for such things as the chemical composition of steel, the shrinkage of cloth, and the physical properties of a material such as strength, elongation, or grain size. And in the third place, 100 per cent inspection is sometimes just uneconomical, as it is for noncritical dimensions of metal parts which, at least within limits, can often be sorted out most effectively in subsequent assembly operations.

TABLE II.—THEORETICALLY EXPECTED RESULTS OF EXPERIMENT FOR $p = 0.17$ AND SAMPLE $n = 10$.

Number of Defectives	Per cent of Samples
0	15.5
1	31.8
2	29.3
3	16.0
4	5.7
5	1.4
6	0.3
7	0.0
	100.0

But as we have seen, sampling has its problems. When we sample, we run up against errors of sampling that are subject to the laws of chance. Let us get five more samples of 10 from our bowl of 200 chips and then examine the results. (Five additional samples of 10 show, respectively, 2, 1, 5, 1, and 3 red chips.) The information from the ten samples of 10 are summarized in Table I and plotted in Fig. 1. This shows variations in results from 0 to 5 defects in a sample—that is, a range from 0 to 50 per cent defective is indicated. Did someone do something wrong? Is it reasonable to expect such a wide range in values? If so, how could the sampling error be reduced?

To answer these questions, we must ask, "What would we expect to get in samples of 10 in a case like this?" Actually, the bowl contained 34 red chips, so that the lot quality, expressed as a fraction defective, was $p = 34/200 = 0.17$, or 17 per cent defective. Knowing this fact, mathematics can tell us just what we should expect in random samples of 10 drawn from 17 per cent defective product. Since the sample size ($n = 10$) is such a small percentage (5 per cent) of the lot size ($N = 200$), we can use the formula for sampling from an "unlimited universe."[5] Thus, the probability of finding m defectives in a random sample of n units drawn from an unlimited universe having a fraction defective, p, is given by the $(m + 1)$th term of the expansion

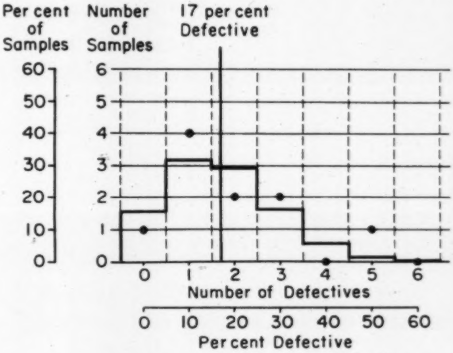

FIG. 2.—Comparing Observed Results (Dots) with Expected Results (Histogram).

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[5] See reference (3), p. 206, or reference (7), p. 44. If n/N is small—0.05 or less, let us say—the lot size can for most practical purposes be considered "unlimited" (infinite), which permits ignoring lot size in calculations.

of the binomial, $(q + p)^n$, that is:

$$C^n_m(q)^{n-m}(p)^m$$

where:

$q = 1 - p,$

$C^n_m = \dfrac{n!}{(n-m)!m!}$, and

$n!$ is "factorial n," which is given by

$n! = (n)(n-1)(n-2) \cdots (3)(2)(1).$

Carrying out this calculation for all values of m, we have the tabulation of Table II. The results have also been plotted as a step diagram or histogram in Fig. 2.

How can we interpret this table and figure? What they say is this: If we repeat this experiment over and over and over again, taking a very large number of random samples of 10 from some 17 per cent defective product, we could expect about 15.5 per cent of the samples to show no defects, about 32 per cent of the samples to show one defect, and so on. This gives the basic notion of probability as we will use it in our discussions—namely, relative frequency of occurrence. Two statements run parallel:

1. In a large number of random samples of 10 drawn from quality $p = 0.17$, we may expect 15.5 per cent of them to show no defects.

2. In a random sample of 10 drawn from quality $p = 0.17$, the probability is 0.155 that we will find no defects.

Whenever we draw a sample, we consider it as just one of the unlimited number of like samples that could have been drawn—that is, conceptually it is a random member of an infinite population of like samples. If many such samples were in fact taken, then we would expect in the long run that 15.5 per cent of them would show no defects. Therefore, the chances are 15.5 in 100, or stated another way, the probability is 0.155, that a single random sample, the one we are about to take, will show no defects.

In our experiment, in which we repeated the sampling operation ten times, we went only part way toward the theoretically infinite number of trials. For this reason our dot diagram deviates to some extent from the theoretical histogram. Were we to repeat the experiment 1000 times, we would expect to get values of observed per cent of samples (dots) much closer to the theoretical values than when repeating only ten times.

The histogram of Fig. 2 can be regarded as the sampling distribution of values of p to be expected in samples of 10 drawn from material of quality $p = 0.17$. It shows at a glance how wide a variation can be expected in sample results for samples of size $n = 10$. To narrow down the variation, a larger sample is needed. In fact, the range of variation is inversely proportional to the square root of the sample size n (still assuming a small ratio, n/N, of sample size to lot size). It is interesting to note how well we came out with the cumulative results for the ten samples of 10, as though this were a sample of 100. We found a total of 19 defects in our ten

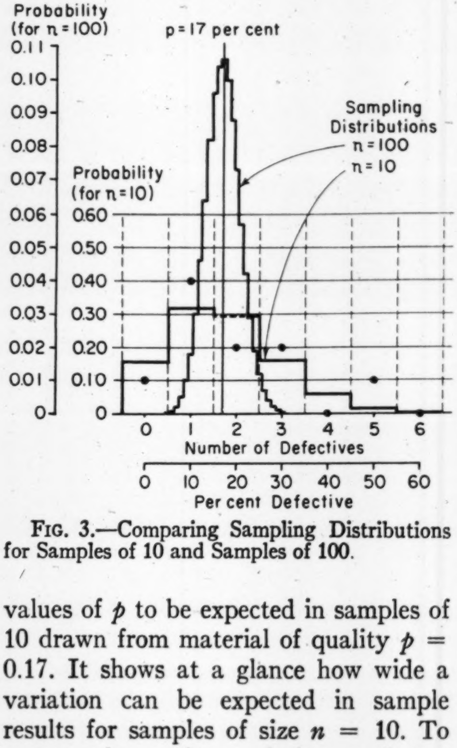

FIG. 3.—Comparing Sampling Distributions for Samples of 10 and Samples of 100.

samples of 10, or an indicated 19 per cent as compared with the true value of 17 per cent defective, a relatively small sampling error. In Fig. 3 is shown the sampling distribution of results for samples[6] of 100, and it is seen that the range of variation is only about one third as great as for samples of 10.

In all of this discussion, we have made an assumption that cannot always be made lightly, namely, that the measurement operation was without error. We presumed that we were using go and not-go gages to determine whether the individual piece parts in our samples of 10 met the specification limits. Individual inspectors' handling of the gages, the failure to maintain gages in the face of wear, burrs, and other factors can of course give biased results, whereby the results of one inspector may be different from those obtained by others. Thus, errors due to the measurement operation may be present in addition to the errors of sampling—something that always requires consideration by the engineer.

Conclusions from Sampling Experiment:

From this experiment we are able to draw certain conclusions that are of general interest wherever we have the problem of interpreting a given set of inspection or experimental data:

1. The sample we draw in the inspection of a lot or from a production line is normally just one of an unlimited number of possible samples.
2. If the material sampled is mixed, or if the sample is drawn by a random operation, then one sample is just as good as another. It is a matter of chance which particular one we get.
3. The sample quality is not necessarily the same as the lot quality. It was impossible in this experiment. The lot was 17 per cent defective, and the sample quality could be only one of the discrete values—0, 10, 20, 30 per cent, etc.
4. Other things being equal and assuming an unbiased measurement operation, the larger the number of units in the sample, the smaller will be the expected sampling error.
5. In inspection work, it is not usually the purpose to obtain an estimate of the lot quality, but rather to provide results that can be used as a basis for action—to accept or to reject the lot.

QUALITY AS A FREQUENCY DISTRIBUTION

Two General Methods of Measuring Quality:

In the experiment just performed, each unit of product was measured by the "method of attributes"—that is, each unit was examined to determine whether it did or did not possess the attribute of conformance to a specified requirement. For this method of measurement, the statistical measure of the quality of a group of things is the fraction defective, p.

Now let us consider a second and perhaps more informative method, namely, measurement by the "method of variables." This consists in measuring and recording the numerical magnitude of a given variable characteristic for each of the items, objects, or individuals in the group under consideration. For this method, there are at least two statistical measures of the quality of a group of things—some measure of average, such as the arithmetic mean, $\overline{X}$, and some measure of spread, such as the standard deviation, σ.

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[6] The distribution curve for $n = 100$ in Fig. 3 shows the scatter to be expected for cumulative samples (ten samples of 10) obtained in the particular manner of the experiment, or for samples of 100 taken without replacement from a much larger lot, so as to have a small ratio, n/N, of sample size to lot size. Samples of 100 taken without replacement from a lot of 200 would have a narrower spread; the standard error of observed values of p for sampling from a finite universe is $\sigma_p = \sqrt{p(1-p)/n}\sqrt{1-n/N}$ where N is the lot size. Only when n/N is small can the second factor be ignored.

Frequency Distributions:

For measurable characteristics, any discussion of quality must deal with variability. Physical and chemical properties of a material vary from spot to spot. The quality of a finished product varies from unit to unit. Thus, when dealing with a quality characteristic of a material or a product, we must deal with variations from test specimen to test specimen, from article to article, and hence from observation to observation. The quality of any collection of product in respect to any measurable characteristic, such as tensile strength of steel wire strand, diameter of shafts, or the transconductance of electron tubes, is fundamentally a frequency distribution, not a single fixed value. Examples are indicated in Fig. 4, where the heights of the ordinates represent the frequency of occurrence of values of the measured characteristic for single units or test specimens.

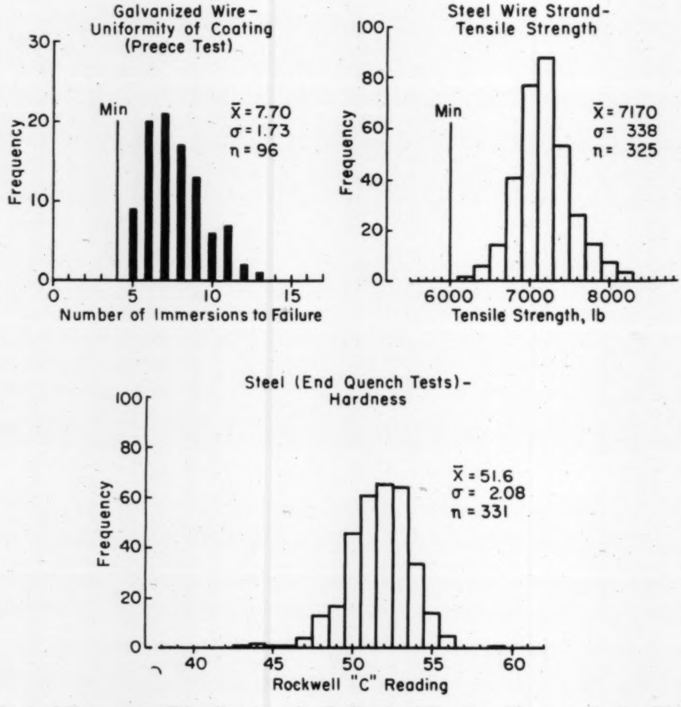

FIG. 4.—Typical Frequency Distributions for Individual Quality Characteristics. The first two examples are from reference (**8**); the third example is from reference (**9**).

Let us take, for example, the breaking strength of $\frac{5}{8}$-in. machine bolts. In preparing to manufacture this type of bolt, the manufacturer sets up a production process that involves materials, machines, and men. This process encompasses a more or less complex system of causes of variation, each element of which contributes to variations in the breaking strength of the individual bolts in the finished product. Prominent among the causes of such variations are the variations in the carbon content of the steel, in the impurities such as sulfur and phosphorus, in the homogeneity of structure from point to point within the material, in the conditions of heat treatment, in the diameter of the rod stock, and in the conditions relating to the forming or machining processes.

Each of these causes, considered independently, contributes a share to the variations of the finished product, and regardless of how refined the production technique may be, there will be a scattering of values of breaking strength around some central value. If each of these causes of variation continues to have the same probability of contributing a given effect, then the breaking strength of the product may be said to be in a "state of statistical control" as defined by Shewhart (2, 10), and the cumulative effect of all the causes can be represented by a frequency distribution, such as that shown in Fig. 5. This distribution can be regarded as a *statistical representation* of the production process, in respect to breaking strength. It has some definite average or arithmetic mean, $\bar{X}'$ (= 13,500 lb), and some definite spread as measured by the standard deviation, σ' (= 950 lb). For any band of values, from 12,500 to 13,000 lb, let us say, there will be a specific value of probability (p' = 0.15) numerically equal to the ratio of the area under the curve within this range to the total area under the curve. This may be thought of as the probability of producing a bolt having a breaking strength in this band or, perhaps more easily, as the expected proportion (relative frequency) of the total bolts that will lie within this band for the production process under consideration. Any change introduced into the process that affects one of the major causes of variability, such as the carbon content or the diameter of rod stock, will be reflected by an increase or a decrease in the average value of this distribution, by a widening or narrowing of its spread, or by both, and as a consequence there will be an attendant change in the value of probability associated with any band, such as the value p' = 0.15 for the band 12,500 to 13,000 lb.

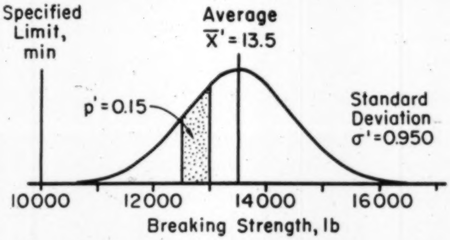

FIG. 5.—Distribution of Breaking Strength—$\frac{5}{8}$-in. Machine Bolts.

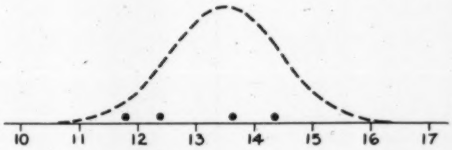

FIG. 6.—Sample of 4 from the Distribution of Fig. 5.

This concept of a state of statistical control might at first glance appear overrigorous, for it may well be argued that it is practically impossible to maintain such a high degree of constancy in the entire stream of product turned out by any industrial process. But we hold this concept as a simple ideal, and use a mathematical model based upon it. First, we use the notion of a frequency distribution, defined by one or more parameters, as existing at any given time. Second, we use the concept of an unchanging distribution symbolizing a *constant system of chance causes*, and set up certain criteria, as with the Shewhart control chart (2), such that (*a*) if the criteria are met, we may with confidence make decisions that are founded on the assumption that the distribution is unchanging, and (*b*) if the criteria are not met, we may take this as an indication of the presence of a findable, or what Shewhart calls an "assignable," cause of variation (2). Thus, in the factory or in the laboratory, when we have a set of observations taken under essentially the same conditions, we may take these as indicative of the underlying distribution of possible observations at the time and for the conditions under which the data were obtained. Or again, if we have a series of samples, each comprising a set of observations and separately judged to be obtained under essentially the same conditions, we can discover something about the behavior of the underlying process, whether it may appropriately be symbolized by an unchanging distribution or by a distribution that is subject to changes due to physical causes that can be found and eliminated.

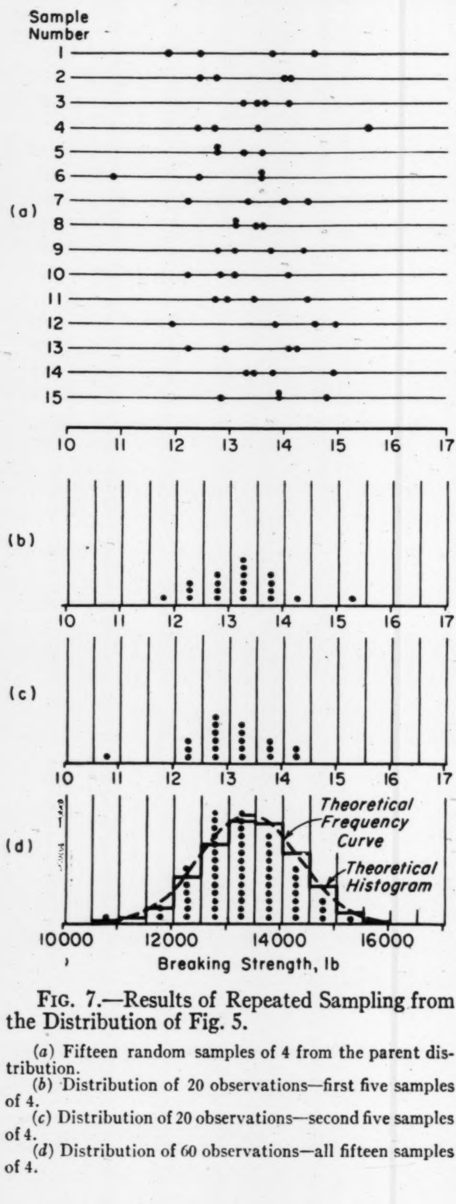

FIG. 7.—Results of Repeated Sampling from the Distribution of Fig. 5.

(*a*) Fifteen random samples of 4 from the parent distribution.

(*b*) Distribution of 20 observations—first five samples of 4.

(*c*) Distribution of 20 observations—second five samples of 4.

(*d*) Distribution of 60 observations—all fifteen samples of 4.

Sampling Variations:

Let us suppose that on a particular occasion a sample of 4 bolts was to be selected at random from the process symbolized by the distribution of Fig. 5. The results of testing the 4 bolts in the sample might appear as the four observations indicated in Fig. 6. These four values would be trying as best they could to portray the underlying distribution shown by the dotted curve. Obviously, they cannot do this very well. Suppose fourteen additional samples of 4 were taken at random from the same universe; the results might appear as shown in Fig. 7(*a*). Here we see considerable variation from sample to sample; no two samples seem exactly alike. Were we to take the total results for the first five samples of 4, the equivalent of taking a random sample of 20 from the universe, and group the observations into cells of 500-lb width, we would get the "observed" frequency distribution shown in Fig. 7(*b*). This is more like the underlying distribution but is not very precise. If another sample of 20 were taken—by collecting together the observations for the second five samples of 4—the result might be as shown in Fig. 7(*c*). This distribution for the second group of 20 observations differs from the first group, as is to be expected. Once again, if we were to group together all of the 60 observations for the fifteen samples of 4, the equivalent of a random sample of 60, the result would be as shown in Fig. 7(*d*). Note how this compares with the theoretical frequency histogram (columns erected on the cells of 500-lb width) and the dotted frequency curve. Even this result is not exact. And in any case, even under the ideal conditions here assumed, where the underlying distribution is really unchanging, we can never know exactly what the distribution is; we can only approximate it. For these ideal conditions, we can, however, approximate it closer and closer as the sample size is increased more and more. We can predict within limits, on a probability basis, just how the observed distributions for lots of 1000 bolts, for samples of 100 bolts, or for samples of 10 bolts, may be expected to differ from this true distribution curve.

To do this we ordinarily find it convenient to express any set of n observed values:

$$X_1, X_2, X_3, \cdots X_n$$

in terms of simple statistics of these values, such as the arithmetic mean,

$$\bar{X} = \frac{\text{sum of observed values}}{\text{number of observed values}} = \frac{\Sigma X}{n};$$

the standard deviation (root mean square deviation of individual values around their $\bar{X}$),

$$\sigma = \sqrt{\frac{\text{sum of (observed value} - \text{arithmetic mean)}^2 \text{ for all observed values}}{\text{number of observed values}}}$$

$$= \sqrt{\frac{\Sigma(X - \bar{X})^2}{n}};$$

and the fraction, p, of the total number of observations that fall inside (or outside) any stated values of breaking strength. When samples are small, $n = 15$ or less, the range, R (algebraic difference between the largest value and the smallest value in the sample), is often used as a measure of spread instead of the standard deviation, σ.

For successive samples, the observed values of $\bar{X}$, σ, and p will fluctuate around the true or objective values $\bar{X}'$, σ', and p' of the frequency distribution representing the production cause system. Figure 8 indicates, for example, the band within which we may expect "practically all" of the observed values of these statistics to fall, under these controlled conditions. The limits of this band are the so-called "3-sigma limits" of variation, which for a normal distribution include 99.7 per cent of the values. These limits are determined from the following formulas:

$$\text{Limits for } \bar{X} = \bar{X}' \pm 3\frac{\sigma'}{\sqrt{n}}$$

$$\text{Limits for } \sigma = c_2\sigma' \pm 3\frac{\sigma'}{\sqrt{2n}} \text{ (approx.)}$$

$$\text{Limits for } p = p' \pm 3\sqrt{\frac{p'(1-p')}{n}}$$

where c_2 is a constant (**4**, p. 63) dependent on sample size:

n	c_2
4..........	0.798
5..........	0.841
10..........	0.923
20..........	0.962

It will be seen that the range of variation of $\bar{X}$, σ, and p is relatively small for large sample sizes; the range actually decreases inversely as the square root of the sample size. This gives the easy-to-remember rule: To cut the sampling error in half, take a sample four times as large.

Suppose that as a result of some manufacturing irregularity the system of causes in the production process were such as to give the objective distribution indicated in Fig. 9, in which 5 per cent of

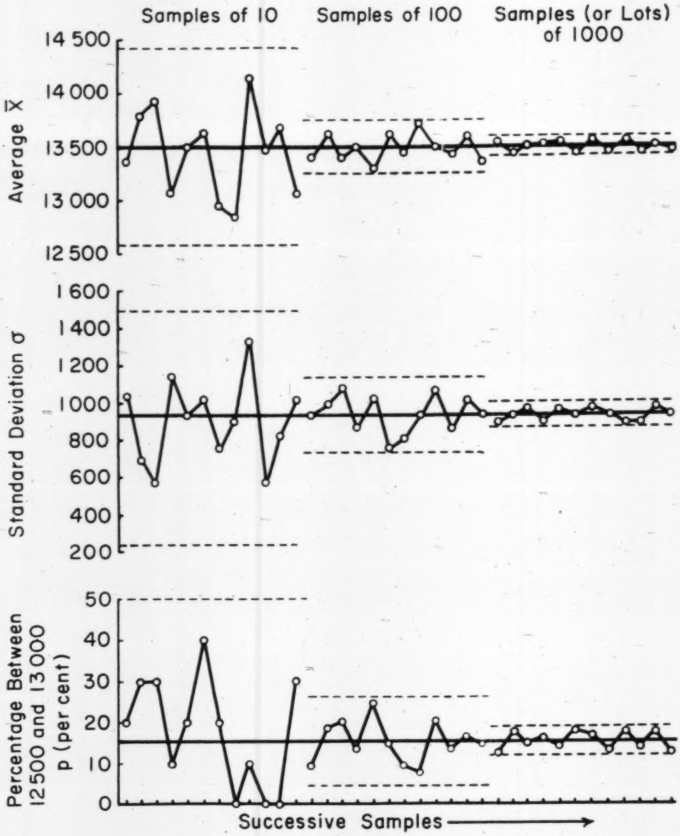

FIG. 8.—Variation in Observed Values of $\overline{X}$, σ, and p for Several Sample Sizes (from Dodge (11)).

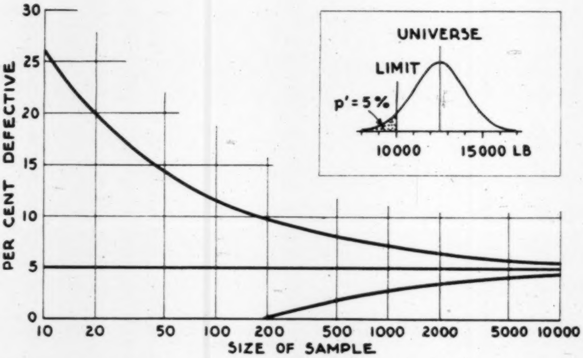

FIG. 9.—Expected Range of Variation in Observed Values of Per Cent Defective—±3-Sigma Limits Around a Level of $p' = 5$ per cent Defective (from Dodge (11)).

the bolts may be expected to have a breaking strength of less than the specified minimum value of 10,000 lb. Then the range of scattering of observed values of per cent defective (per cent of bolts having strength less than 10,000 lb) around the 5 per cent level would be dependent on the sample size in the manner shown. For example, if a sample of 180 bolts were tested, the results might show from 0 to 10 per cent of them with breaking strength below 10,000 lb, even though 5 per cent of the universe were actually below this value.

Some knowledge of the variations to be expected in sample results is essential to meaningful interpretation of the data that are dealt with in engineering problems.

SAMPLE AND UNIVERSE

Sample Results in Practice:

The charts of Figs. 8 and 9 indicate what may be expected under theoretically ideal conditions—sampling from a universe whose distribution is known exactly. The use of probability theory under such conditions involves reasoning from the general to the particular, that is, from a known universe to unknown samples.

In the practical case, we never know exactly what the universe is. Instead, we must use inductive reasoning—the process of inferring the general from the particular. The sample results are given—what can we conclude regarding the universe whence the sample came?

Let us suppose that it is desired to find out something about the average breaking strength for a lot of several hundred bolts made during a production run. Since the test is destructive, only a limited number can be tested. If this is an isolated lot, rather than one of a series of lots made under like conditions, we are forced to judge the quality of the entire lot of bolts from the results of testing only a few. Suppose that ten bolts are selected "at random" from the lot and tested by standard method of test, giving the following ten observed values of strength, in thousands of pounds: 12.6, 13.0, 13.8, 12.4, 13.4, 13.2, 12.9, 12.7, 12.2, 14.3. Is the average strength of this group of 10 bolts—13,050 lb—the same as the average of the lot? Probably not. This particular group of 10 bolts is only one of a very large number of such groups of 10 that we might conceivably draw at random from the lot. Just as with our sampling of metal parts by the method of attributes described above, the results of a second sample of 10 would probably not be the same as the results for the first sample of 10, nor the same as the average of the lot. The engineer is constantly faced with the problem of drawing conclusions regarding the *whole*, or of deciding what action should be taken on the whole, when he has measured only a *part*. Such conclusions and decisions are subject to error because of the uncertainty that attends incomplete information.

Limited and Unlimited Universes:

In this particular case, the group of 10 bolts is considered as a *sample*, and the entire lot of several hundred bolts from which the sample bolts were selected is considered as a "population" or "universe." Here, where the question asked relates to the average strength of the lot, the universe is restricted to the finite number of bolts in the lot under consideration, and may accordingly be thought of as a *limited* universe. But there is another way to look at this selfsame sample. Were the sample of bolts to be regarded as a sample from the production process for the purpose of drawing some conclusion regarding the system of causes that affected the breaking strength at the particular time this lot was produced, then the universe under consideration would be the hypothetical infinite number of bolts that the process might conceivably turn out under the same essential conditions, and as such would be regarded as an infinite or *unlimited* universe.

Depending on what the problem is, what type of conclusions are to be drawn, or what type of action is contemplated, a sample may be regarded either as a sample from a limited universe (to provide information or a basis for action regarding the finite quantity at hand), or as a sample from an unlimited universe (to provide information or a basis for action regarding the production process or system of causes) (see Fig. 10).

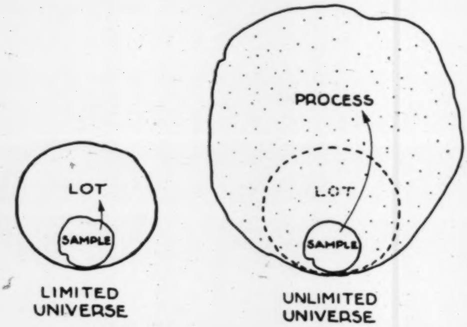

FIG. 10.—Two Purposes of Sampling: To Discover Something About a Lot or to Discover Something About a Process.

This is a very important distinction and has a direct bearing on the problems of collection and interpretation of most engineering data. Let us assume, for example, in a research project, interest centers on the physical properties of a new type of material being developed in the laboratory. A batch of the new material has just been made up, and it is planned to take a sample of several specimens from the batch and to make certain standard tests on them. The purpose for making such tests might fall into either one of the two general categories mentioned above, and the manner of collecting and interpreting the experimental data would depend on the specific purpose under consideration. Thus, on the one hand, the questions to be answered might be: Shall I use this batch for making up certain experimental electronic parts? Are the physical properties right for this purpose? Here the test data would be used to provide an estimate, within suitable limits, of the quality of the particular batch of material (limited universe) at hand. On the other hand, the question to be answered might be: When making this batch, were the time and temperature constants of my process correct; or should I modify them and make another batch to get the physical properties that are closer to what I expected? Here the test data would be used to provide information regarding the process (unlimited universe), say the appropriateness of certain chosen processing factors. In this case, the test data for the current batch might advantageously be compared with the test data for earlier batches made under the same or different known process conditions.

With respect to inspection and testing work in the factory, these same two distinct purposes are recognized, as stated in American War Standard Z1.3 (6):

"PURPOSE A. To provide a basis for action with regard to the product already at hand; as for instance, to decide whether the particular article or lot of product at hand should be allowed to go out, or some alternative disposition made (inspected further, sorted, repaired, reworked, scrapped, etc.).

"PURPOSE B. To provide a basis for action with regard to the production process, with a view to future product; as for instance, to decide whether the process should be left alone, or action taken to find and eliminate disturbing causes."

Routine lot-by-lot acceptance sampling plans are often used primarily with the first purpose in mind, although the inspection results can usually be used collectively for the second purpose. Control chart procedures and other statistical techniques employed in conjunction with designed experiments are commonly used for the second purpose.

In other fields, too, this distinction of purpose in a problem is important. Deming points this out in his paper, "On the Distinction Between Enumerative and Analytic Surveys" (12), where the word "enumerative" has reference to a finite quantity (limited universe) and "analytic" to a cause system or production process (unlimited universe). He mentions, for example, a marketing survey to provide an estimate of the number of people who prefer to use ground coffee at home rather than soluble coffee. An enumerative question would be: *How many* prefer to use ground coffee, and how many prefer soluble? An analytic question would be: *Why* does a larger proportion (or smaller proportion) prefer to use ground coffee? The latter inquires into *reasons*, into systems of causes.

Deming continues:

> "In the enumerative problem some action is to be taken because the frequency of some particular characteristic of the universe is found to exceed some critical value. The crop of wheat, according to a sample survey, turns out to be large or small. As a consequence the market goes down or up, and production of meat, cereal products, and of substitutes shifts one way or another because of this information. The census or perhaps a sample study of birth registration shows that in a particular city the number of children in the primary schools will be much greater in four years than now. Bonds are issued; work commences on a new school building. Such problems are enumerative because they depend purely on an enumeration of the number of people in an area or the inventory of grain or the production of grain . . . They do not involve the analytic question of why all these people are there or why the crop this year is what it is.
>
> "In the analytic problem the action is directed at the underlying causes. We may run an experiment with a group of test animals or with patients in the hospital, but when we generalize from these tests, we are thinking of the production process: what will it produce in the future? The present tests are important only because they help us to prescribe or to modify the treatment for future use."

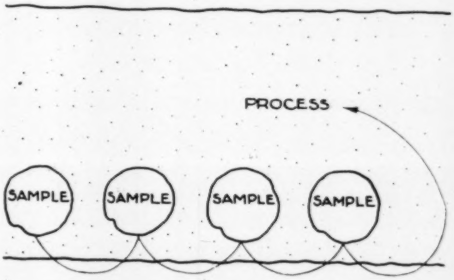

FIG. 11.—Repetitive Sampling to Discover Something About the Behavior of a Process.

So in our engineering problems, in research and development, in production, and in inspection activities we do well to keep clearly in mind the two basic purposes for collecting data and the corresponding two basic attitudes in interpretation.

Repetition Sampling—Quality Control:

Let us suppose the set of observations at hand was one of a series of such sets obtained successively from a continuing manufacturing process, or during the course of a continuing experiment in the laboratory (see Fig. 11). Here the *order* of the data becomes important. The results for the whole series of samples can be used to draw conclusions regarding the dynamic behavior of the underlying process—whether it is stable or is changing as time goes on.

Certain statistical techniques, notably the Shewhart control chart (2), are particularly applicable to such situations and make use of the important information contained in the *order* in which the data are taken. If there is lack of stability, control charts give clues to the causes and thus facilitate their elimination.

This is a basic purpose of Shewhart's "operation of statistical control" (10): to take repeated samples from a process; to take action when control criteria are not met by investigating, finding, and eliminating causes; to repeat this process over and over again, in order finally to have a constant system of chance causes and resultant quality that is consistently uniform, so that one may with confidence predict what quality will be obtained tomorrow from the uniformities of the past. The operation of statistical control is primarily a procedure for hunting, finding, and eliminating assignable causes.

Shakespeare seems to have provided the basic philosophy in *Hamlet*, Act II, Scene 2:

> "Find out the cause of this effect,
> Or rather say the cause of this defect,
> For this effect defective comes by cause."

More specifically, there are two basic and alternate interpretations of the plottings on a control chart that should be kept in mind:

(*a*) If the chart gives an indication of lack of control: Take action, seek out, and eliminate the cause.

But equally important:

(*b*) If the chart gives no indication of lack of control: Leave the cause system (the process) alone!

This duality is surprisingly well brought out in the teachings of Mother Goose, in the 1916 Rand McNally edition of *The Real Mother Goose*:

> "For every evil under the sun,
> There is a remedy or there is none.
> If there be one, seek till you find it.
> If there be none, never mind it."

Statistically controlled quality is one of the ideals of quality engineering. Once it has been attained by the control chart technique (Shewhart's "operation of statistical control"), we have a stable statistical universe. Stability of this kind makes it possible to predict on a probability basis what can be expected tomorrow. Briefly, it makes valid prediction possible.

Shewhart explains (14) that the "theory of statistical control" is concerned with the development of "a scientific method of making the most efficient use of raw materials in the production of things to satisfy human wants; a scientific method that takes into account the fact that inferences can only be probable; a method that will help us to obtain maximum validity in the field of prediction and that will provide a rational routine for minimizing variability in the repetitive act of production through the detection and removal of assignable causes of variation." In referring to the contributions of statistical control (14), he lists six ways in which the advantages are most felt:

> "1. Reduce the amount of inspection;
> 2. Minimize the number of rejections and hence the quantity of scrap;
> 3. Maximize quality assurance;
> 4. Increase output of goods of standard quality;
> 5. Increase employee satisfaction; and
> 6. Minimize tolerance ranges."

On the Inclusiveness of the Universe:

Up to this point the term "sample" has been used in the sense of a sample of physical articles or things from a larger collection, real or hypothetical. The term "sample" is also used in statistical work in the more inclusive sense of a *sample of observations*. In fact, in most types of engineering work it is profitable to consider any set of observations obtained in production, or experimentally in the laboratory, from the second of the two points of view mentioned above under Limited and Unlimited Universes, namely, as a sample from a hypothetical unlimited universe of possible observations, with a view to discovering something about the underlying causes that gave rise to the data at hand

Note that each observed value—the measured breaking strength of a machine bolt, for example—is rarely if ever exactly equal to the true value of breaking strength; errors in the measurement operation are involved. The observed values of breaking strength for a sample of machine bolts thus depend not only on the physical quality of the sample bolts themselves as contributed by the production process, but also on the following:

(*a*) On errors attributable to the particular testing machine used, whether it be in calibration or not;

(*b*) On the actual physical conditions of test, differing perhaps in some degree from those specified, and perhaps subject to drift or change during the course of the tests; and

(*c*) On the observer himself, his skill or lack of skill, experience or lack of experience, which introduce personal errors or variations in his method of conducting a test, in his method of reading the scale, and perhaps even in his act of recording the test results.

Thus the system of causes represented by the statistical data at hand includes all of the many factors of variation in both the production process and the measurement process. When we consider that an actual physical sample is only one of a large number of possible samples, we see that the actual sample of observations is, in fact, a sample of a hypothetical universe of observations obtainable under the same conditions with respect to:

(*a*) The production process, including
  (1) the particular raw materials used,
  (2) the production machines used,
  (3) the conditions of manufacture (processing time, temperature, etc.),
  (4) the skill and workmanship of production personnel;

(*b*) the method of selecting the sample; and

(*c*) the measurement process, including
  (1) the procedural method used,
  (2) the measuring device or equipment used,
  (3) the conditions of test, and
  (4) the observer who conducted the tests and made the measurements.

Practically every set of engineering data is the end product of a wide variety of causes, encompassing materials, machines, and men. A basic change in any one of the many factors can constitute setting up a different statistical universe of possible observations. The causes we seek may be in the process, or they may be in the measurement operation.

In interpreting the results of a sample of measurements from some kind of repetitive experiment or process, conclusions may be expected to be meaningful if the many conditions affecting the measured characteristic under study remain essentially the same. In this circumstance there is *a* universe, and from our data we may properly infer something about the quality of that universe, conceived of as

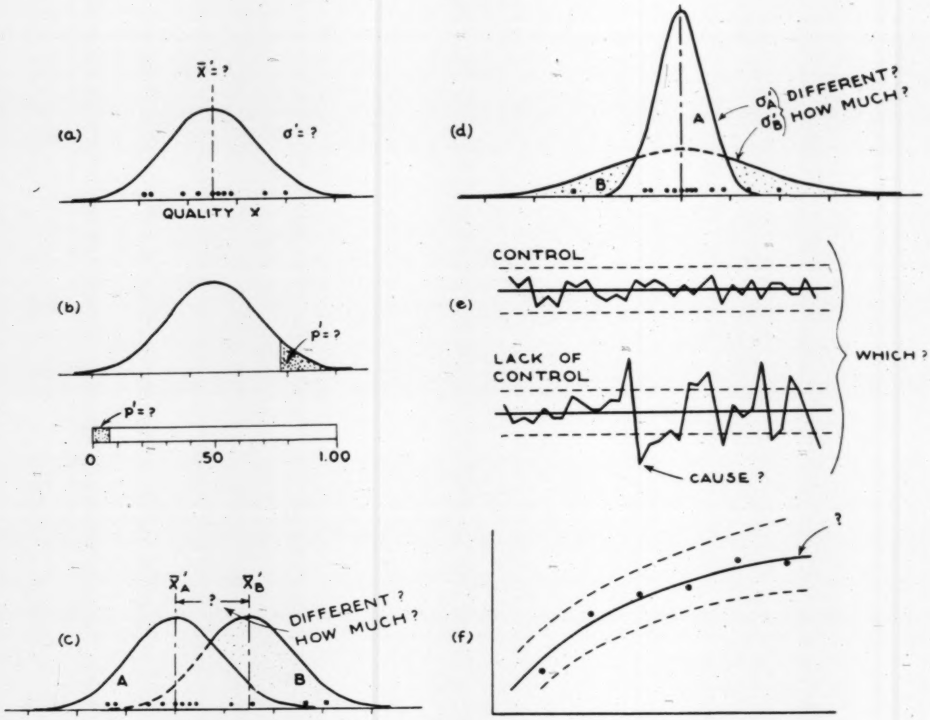

FIG. 12.—Some Problems Involving the Use of Statistical Methods.

stable and hence discoverable, were we to carry out further sample tests of the same kind.

But having drawn certain conclusions from an experiment made under one set of conditions does not permit us to draw conclusions for another set of conditions. As expressed by D. J. Finney (15):

> "A standard error calculated from the internal evidence of one experiment relates only to repetition under the same conditions, using either the same subjects and materials or others that can be regarded as random samples from the same population as were those in the original experiment."

INTERPRETATION OF DATA

Engineering Problems:

Many engineering problems fall into a number of specific categories with respect to the interpretation of data, as indicated in Fig. 12.

(*a*) A common problem is one of discovery regarding a distribution. What is the true average value, $\bar{X}'$; what is the true standard deviation, σ'; what is the general shape of the distribution, for the product or the process? These questions might be raised with respect to such characteristics as the tensile strength of a wrought copper-base alloy, the corrosion resistance of a protective coating, the cleavage tests of an adhesive.

(*b*) Again, the question might be: What is the expected percentage of the product above a stated maximum limit—for elongation, for example? Or (as indicated by the bar in Fig. 12(*b*)) what is the expected percentage of product that will fail to meet some attributes test, a specified bend test, let us say?

(*c*) In comparing two products, or the effect of two treatments, the question might be: Is treatment *A* better than treatment *B*, or is product *A* better than product *B*? And if *A* is better than *B*, how much better is it? And with what degree of confidence may I conclude that *A* is *x* units better than *B*?

(*d*) Often we are concerned with the relative variability of two products, two methods, two procedures. The question might then be: Is the precision of test method *A* better than that of test method *B*? If it is better, is it enough better to warrant its substantially greater cost?

(*e*) In production engineering, this question repeatedly comes up: Is quality controlled? Or are the frequent trouble situations due to lack of control in process? If there is lack of control, what is the cause?

(*f*) In developing new materials or processes, a frequent question is: What is the relationship between factors *a* and *b*? How does tensile strength vary with successive intensities of heat treatment?

The answers to these questions depend to a surprising degree on the appropriate use of certain statistical methods. The literature is rich in these methods, varying from the simplest to the most complex and including such subjects as simple graphical methods, frequency distributions, estimation, confidence limits, tests of significance, control chart techniques, acceptance sampling plans, design of experiments, analysis of variance, and decision functions. We can hope to touch on only a few methods here, to indicate some of the factors involved in the interpretation of data.

Qualitative Information:

Our knowledge of the physical quality of a product or material is derived in large measure from the interpretation of quantitative data. However, the data constitute only a *part* of the information used in interpretation; the judgments that are made depend, as well, on all available relevant information with respect to the precise conditions under which the product was manufactured, the precise conditions under which the data were obtained, etc. Such relevant information is mostly qualitative and is not capable of numerical expression. Often, too, in production and quality control work, prior numerical data have an important influence on the conclusions drawn, as suggested in Fig. 13.

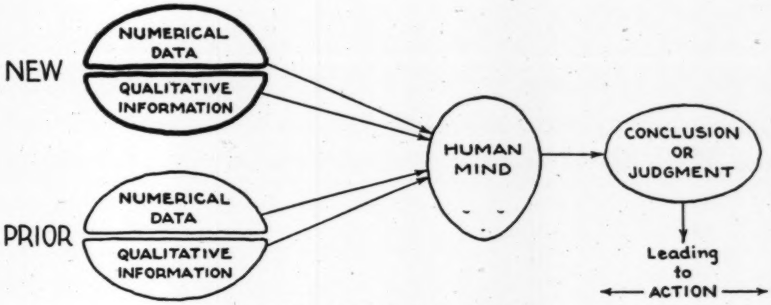

FIG. 13.—Interpretation of Data.

In interpretation, the engineer assumes the role of a judge, takes the immediate numerical data, gathers together as much pertinent evidence as he can, weighs the evidence, and renders his decision. Of greatest importance is the collateral information on precisely the field to which the data apply: What were the specific conditions of production? What machines were used? Who selected the sample units for measurement? What was the method of measurement? Were the measurements free from bias? Who did the measuring? What about prior information? Who got the earlier data? When, how, and what were the conditions?

Interpretation relates to the universe of causes, including all of these many factors. Which are important, which are not, is for the engineer to decide. All through these questions we note the recurrence of *human beings*—an ever-present general factor that affects the thing measured, the data obtained, and the interpretation itself.

The need for including available relevant information along with numerical data is recognized in the work of the American Society for Testing Materials and is expressed as follows in the ASTM Manual on Quality Control of Materials (**4**, pp. 33, 34):

> "Among the specific things that may be presented with ASTM data to assist others in interpreting them or to build up confidence in the interpretation made by an author are:
>
> "1. The kind, grade, and character of material or product tested.
>
> "2. The mode and conditions of production, if this has a bearing on the feature under inquiry.
>
> "3. The method of selecting the sample; steps taken to insure its randomness or representativeness.
>
> "4. The specific method of test (if an ASTM or other standard test, so state; together with any modifications of procedure).
>
> "5. The specific conditions of test, particularly the regulation of factors that are known to have an influence on the feature under inquiry.
>
> "6. The precautions or steps taken to eliminate systematic or constant errors of observation.
>
> "7. The difficulties encountered and eliminated during the investigation.
>
> "8. Information regarding parallel but independent paths of approach to the end results.
>
> "9. Evidence that the data were obtained under controlled conditions; the results of statistical tests made to support belief in the constancy of conditions, in respect to the physical tests made or the material tested, or both.
>
> "Much of this information may be qualitative in character, some may even be vague, yet without it the interpretation of the data and the conclusions reached may be misleading or of little value to others."

Considering the problems of quality control, and the importance of the information contained in the "order" of the individual measurements in a group, Olmstead (**16**) has this[7] to say:

> "Quality Control has introduced the concept of assignable cause and insists that all data to be helpful should include sufficient information to permit detection and identification of such a cause. On this basis, all good data should include:
>
> "1. The Order, i, associated with each measurement.
>
> "2. The Condition, C_i, under which each measurement was taken.
>
> "3. The Observer, H_i, the human being who made the measurement.
>
> "4. The Time, t_i, when each measurement was made.
>
> "5. The Numerical Value, X_i, of each measurement."

Prediction:

On the general subjects of interpretation of data, prediction, and knowledge, I would like to recommend to the engineer, as "must" reading, the third chapter of Shewhart's book, "Statistical Method from the Viewpoint of Quality Control" (**10**).

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[7] Consistent with Shewhart (**10**, p. 89).

With respect to experimental and test data generally, Shewhart points out that "every meaningful interpretation involves a prediction." When on the basis of past tests and other information we assert that a particular line of product from source A is of good quality, we are predicting what may be expected in future deliveries. Or again, if we assert, on the basis of what we have observed in the past, that Jack is a dependable worker, then we are in effect predicting that Jack will do a good job, and what is expected of him, in future assignments. Uniformities of the past provide a basis for predicting the future.

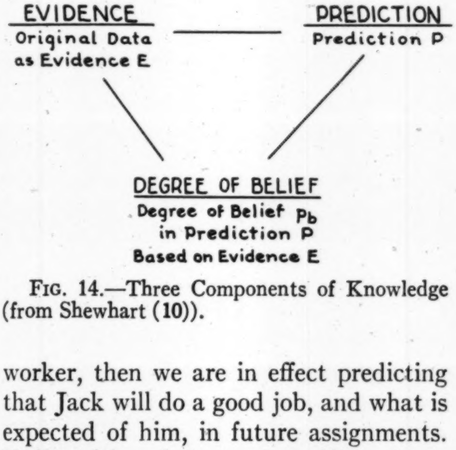

EVIDENCE
Original Data as Evidence E
PREDICTION
Prediction P
DEGREE OF BELIEF
Degree of Belief p_b in Prediction P Based on Evidence E

FIG. 14.—Three Components of Knowledge (from Shewhart (**10**)).

But a prediction by itself does not constitute knowledge. Shewhart (**10**, pp. 101, 103) states: "The scientific analyst must present his evidence along with his predictions if he is to present his results as knowledge," and "to every prediction there corresponds a certain degree of rational belief." As indicated in Fig. 14 (**10**, pp. 85–86), there are three important components of knowledge: "(*a*) the data of experience in which the process of knowing *begins*, (*b*) the prediction P in terms of data that one would expect to get if he were to perform certain experiments in the *future*, and (*c*) the degree of belief p_b in the prediction P based on the original data or some summary thereof as evidence E." Now this item, degree of belief, p_b, is not something that we know how to measure quantitatively, and the whole discussion above may appear to the engineer to be abstract and on the whole rather impractical. But in terms of everyday experience, these concepts are most useful and practical as Shewhart indicates by the following (**10**, p. 86):

> "For example, I might say, 'It is going to rain day after tomorrow.' That statement has a definite predictive meaning in the sense that you can test it in the future. However, it does not convey much knowledge, since I have no standing as a weather prophet. You may therefore ask what makes me think that it is going to rain day after tomorrow. That is, you *ask for my evidence*. Given the evidence, there is presumably a certain degree of belief, p_b, however small, that may rationally be held in my prediction. *The evidence as well as the prediction must be considered*."

This shows how one may make a meaningful scientific statement without conveying much if any knowledge. As a recognized expert, one may be able to get by with presenting conclusions or predictions without much supporting evidence, but the soundest method, the one that will be most widely accepted, is to present both quantitative and qualitative information sufficient to serve as an adequate base for technical conclusions.

An example from the medical profession may be of interest. In the early 1920's, during development work on a multiple electrical stethoscope, I had occasion to study with Dr. Richard C. Cabot, outstanding heart pathologist, the abnormal heart and chest sounds for a number of patients in the Massachusetts

General Hospital in Boston. We were analyzing the frequency content of the sounds, with particular emphasis on heart murmurs, and I was fascinated with Dr. Cabot's interpretations of what we jointly heard in our stethoscope tubes. I remember one case in which he was especially interested, a faint mid-diastolic murmur, which appeared from time to time. I asked how he could judge that this was so serious from the very soft, barely-perceptible, "blowing" sound that we heard. "Oh," he said, "it's the history that counts! The murmur is only part of the evidence. But this particular sound coupled with this particular history is highly significant." And he indicated that for heart murmurs generally, prior data, in addition to current data, were usually essential for valid diagnoses. In retrospect, this case illustrates two important points. First of all, I had a very high degree of belief, as would anyone else, in the conclusion that this was a serious case; his nation-wide reputation served as authority, and I needed no details. Second, in the medical world, as in quality engineering, past history, in its relation to current observations and measurements, is usually of prime importance in drawing conclusions, in making predictions, or in making decisions for action regarding underlying systems of causes.

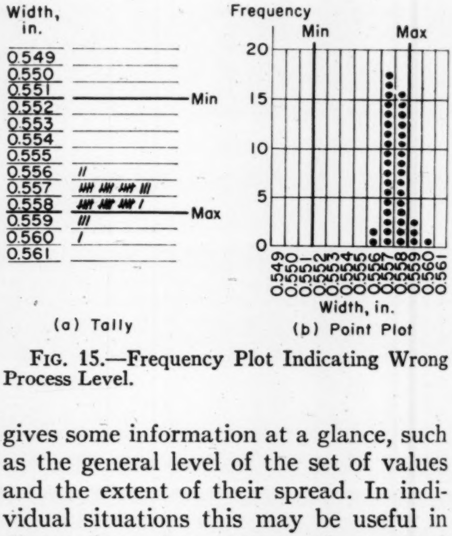
TABLE III.—ORIGINAL DATA—MEASURED VALUES OF SLOT WIDTH, IN.

Sample of 40 Piece-Parts.

0.556	0.557	0.557	0.558
0.557	0.557	0.559	0.557
0.557	0.557	0.559	0.557
0.558	0.558	0.557	0.560
0.558	0.558	0.558	0.557
0.557	0.558	0.557	0.558
0.556	0.557	0.557	0.557
0.558	0.558	0.558	0.558
0.557	0.557	0.557	0.558
0.558	0.559	0.558	0.558

FREQUENCY DISTRIBUTIONS AS AN AID TO INTERPRETATION

Often classifying a set of observations into cells and plotting them into a form of a frequency distribution will provide the engineer with all that he needs for useful interpretation. Let us assume the raw data consist of a set of 25 to 50 observations representing one measurement on each of a like number of product units or specimens. The mind cannot grasp in its entirety the meaning of so many numbers. But the graphical arrangement of a frequency distribution gives some information at a glance, such as the general level of the set of values and the extent of their spread. In individual situations this may be useful in discovering the nature of reported trouble and may serve as a guide for action.



(a) Tally (b) Point Plot

FIG. 15.—Frequency Plot Indicating Wrong Process Level.

For example, Table III gives the measured values of a dimension for a sample of 40 piece parts taken at one time from a production line. The specification gives limits of 0.558 in. max and 0.552 in. min and requires measurement or gaging "to the nearest 0.001 in." Looking at numbers in Table III does show that some values exceed the specification maximum limit, but it requires real mental effort to get even the roughest idea of how bad the situation is. We are all picture-minded. Ideas can be imparted to others and understandings reached more easily if we can present a story in graphical form.

Figure 15 gives (*a*) a simple tally and (*b*) also a point-plot of the 40 observations for the 40 piece parts. From a glance at this figure and without further analysis of the data, it may be concluded that the general level of the distribution is too high. Having first satisfied himself that the data are good data—that the sample was properly selected for the purpose at hand, that a reliable observer made the measurements, and that a good micrometer, free from bias, was used—the engineer can fairly safely conclude that what is needed is an adjustment of the process so that its average will be more nearly centered between the maximum and minimum limits. It would appear, too, that the spread is small enough so that if corrective action were taken to center the process and to maintain it there, there would be few, if any, failures to meet the limits.

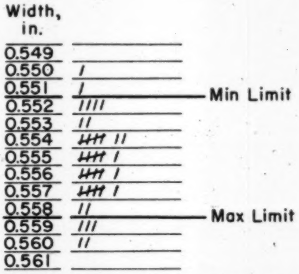
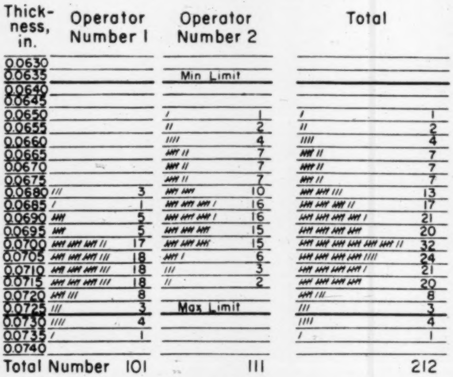


FIG. 16.—Frequency Plot Indicating Process Spread is Too Great.

On the other hand, if the frequency distribution for the 40 parts were as shown in Fig. 16, trouble of quite another type would be indicated. Depending on how the sample had been selected, it might indicate either (*a*) that the inherent spread (natural tolerance) of the process was too great for the specified limits, or (*b*) that the process level was unstable—subject to wandering. If the sample of 40 parts were a group of parts that had been made consecutively, then (*a*) would be indicated. In this case a fundamental change in the process would be necessary, a more precise machine-tool used perhaps, if it were desired to have all parts meet the limits as they came directly from the machine. Without some such action, it would be necessary to invoke a 100 per cent inspection of the parts for this dimension and sort out the nonconforming ones. If the sample of 40 were parts that had been selected at random from the entire output of a day's run, then either (*a*) or (*b*) might be indicated. A decision between (*a*) and (*b*) probably could not be made from the results of a single sample; several samples, in which the *order* of the data by time (also by source if several machines were involved) was preserved, would probably be needed.

A frequency distribution as such, without information regarding how the samples were selected and the conditions under which the observations were taken, is generally of limited value as a guide to action. On the other hand, it is often possible to obtain much information of value from frequency distributions if care is taken in planning the collection of the data and in selecting the samples, to keep as separate groups the various portions of the data which represent different times, sources, and conditions which *may* have a bearing on the quality feature under consideration.

Example.—In the sampling inspection of hard-rubber number plates used on switchboards, trouble was experienced with excessive lot rejections. Inspection was by the method of attributes, and a principal cause for rejections was an excessive percentage of defects with respect to oversize thickness. It was decided to make an investigation by the method of variables to provide information on the pattern of variation in thickness. Thickness is controlled by a grinding operation. Two grinding operators were involved, but their outputs were normally merged. It was decided to take, from the output of each of the two operators, a sample of about 100 number plates and measure them for thickness to the nearest 0.0005 in. This was done under the direction of the engineer running the investigation, who himself selected the samples. The results were recorded on a tally sheet; the actual distributions are shown in Fig. 17. From a glance at these results, the principal cause of the trouble was obvious. Operator No. 1 was responsible; the level of average thickness for her product was too high, giving an appreciable percentage of number plates outside the maximum limit. An adjustment in her grinding technique was made, bringing the average thickness of her product closer to the center value between the limits, and the trouble was cleared.



Thickness, in.	Operator Number 1	Operator Number 2	Total
0.0630			
0.0635		Min Limit	
0.0640			
0.0645			
0.0650		1	1
0.0655		2	2
0.0660		4	4
0.0665		7	7
0.0670		7	7
0.0675		7	7
0.0680	3	10	13
0.0685	1	16	17
0.0690	5	16	21
0.0695	5	15	20
0.0700	17	15	32
0.0705	18	6	24
0.0710	18	3	21
0.0715	18	2	20
0.0720	8		8
0.0725	3	Max Limit	3
0.0730	4		4
0.0735	1		1
0.0740			
Total Number	101	111	212

FIG. 17.—Grinding Operation on Hard Rubber Number Plates.

Two lessons can be learned from this example. First, the location of the cause of trouble is often the result of successful planning of an investigation by one familiar with the process. Here the engineer, after a study of the process, decided that separate samples should be taken from the two operators, recognizing that this was a *possible* source of the unknown trouble. Had a sample of the merged output of the two operators been taken, the resulting distribution would have looked something like the "total" distribution of Fig. 17. This looks like a smooth distribution, might (erroneously) have been considered a single universe, and as a consequence might have prompted a recommendation that the grinding operation be adjusted for both operators. This could well have upset the good work being done by operator No. 2 by bringing in a new type of defect, underthickness, and the problem would not have been solved.

Secondly, the apparent smoothness or single-peakedness of a distribution is no guarantee that there is but a single universe. The "total" distribution of Fig. 17 looks quite smooth and of typical form, yet it actually is a compounding of two quite different distributions (universes).

It is noted that a double-peaked distribution can sometimes be used as an indication of two systems of causes (two universes) if the number of observations is large, say well over 100. This may not be done safely, however, unless the two peaks are well formed and clearly separated.

While frequency distributions *can* be used in some cases as a basis for action, care should be exercised to keep the data in separate subgroups, each identified by the conditions with which it was associated, to permit intercomparisons for the discovery of differences that may explain causes. Empirical analysis of a causal system depends upon such identification. Engineering judgment, control charts, and designed experiments all depend upon data that preserve the identity of source as to men, machines, and material.

And again, instead of taking a single large sample for each of the separate conditions under study, it is usually better from the standpoint of locating causes to take, in some ordered sequence, a series of small samples (four or five observations each) for each of the conditions. Data in this form lend themselves to analysis by the control chart, a technique that provides a basis for assessing stability, that is, for determining whether for each condition there does, in fact, exist *a* universe in the probability sense, and hence whether one can safely draw conclusions based on such a premise.

ESTIMATES AND CONFIDENCE LIMITS

Point Estimates:

Although we usually take data as a basis for some decision or some action, sometimes we wish specifically to obtain estimates of the parameters of the universe that is represented by the sample data at hand.

Let us suppose that we have a sample of 10 bolts selected at random from a lot suspected to be of subnormal quality and that these have been tested for breaking strength by a standard method of test. The observed values of breaking strength, in thousands of pounds, are: 10.8, 9.6, 10.6, 11.4, 9.7, 10.7, 10.4, 10.9, 10.2, 11.7. From these data we wish to estimate some of the more important characteristics of the lot, or universe, from which the sample was drawn. In the interests of simplicity here, a Normal distribution will be assumed.

The section on Sampling Variation mentioned several statistics that may be computed from the sample values, such as:

$$\bar{X} = 10.60, \sigma = 0.632, R = 2.1, \text{ and } p = 0.20.$$

The value of p is the proportion of bolts having breaking strength values less than 10,000 lb, the specified minimum limit.

$$\begin{aligned} \text{Now } \bar{X} &= 10.6 \text{ is an unbiased estimate of } \bar{X}', \\ \frac{\sigma}{c_2} &= 0.685 \text{ is an unbiased estimate of } \sigma', \\ \text{or} \quad \frac{R}{d_2} &= 0.682 \text{ is an unbiased estimate of } \sigma', \\ p &= 0.20 \text{ is an unbiased estimate of } p' \end{aligned}$$

where:

$\bar{X}'$ = the universe average,

σ' = the universe standard deviation, and

p' = the universe fraction below 10,000 lb.

NOTE.—Values of c_2 and d_2 are given in the ASTM Manual on Quality Control of Materials (**4**, p. 62).

The estimates of the preceding paragraph are called "point estimates." But how good are they? How close to the universe values are they? Since point estimates carry no hint of their goodness, another type of estimate, an "interval estimate," is often used.

Interval Estimates—Confidence Limits:

The interval estimate just referred to is called the "confidence interval." Instead of providing a single value as the estimate of the unknown parameter, it gives an interval or range of values and says only that the true value is somewhere in this interval. As Bross (**15**, p. 234) says: "A confidence interval is a rather cagey statement about a parameter." It has an operationally verifiable meaning—one that can be checked experimentally no matter how small the sample size; however, it may not be very useful if the sample size *is* small.

"Confidence limits" define the boundaries of the interval; the length of the interval depends on the "confidence coefficient" chosen. A confidence coefficient of 0.95 (or 95 per cent) is commonly used in engineering work, which means that the user has chances of 95 in 100 of being correct when he makes the statement: "The universe value lies within these (95 per cent confidence) limits." For the problem of the bolts under discussion, the statement for 95 per cent confidence limits would be: The universe average value of breaking strength is somewhere between 10,120 and 11,080 lb. If the engineer wished to have a smaller risk of an incorrect statement, he could use 99 per cent confidence limits, but then the interval would be considerably wider—9920 to 11,280 lb, an increase of about 40 per cent.

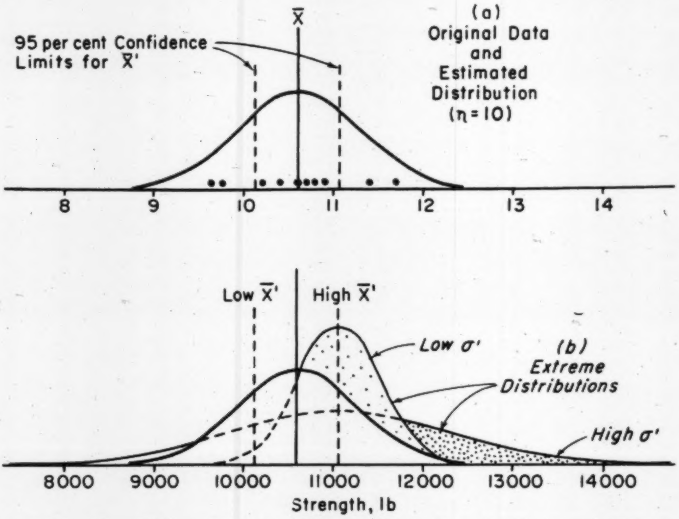


FIG. 18.—Effect of Errors of Estimation—Sample Size, n = 10.

If an engineer goes through life using 95 per cent confidence limits in many problems like the above, and makes the above kind of statement in each case, he can expect that his statements will be correct 95 times in 100, provided certain conditions (**4**, pp. 42–43) assumed in determining the constants mentioned above are met, namely,

(*a*) (For limits for $\bar{X}'$ and σ'): The distribution of X for the universe sampled is approximately Normal, and

(*b*) (For limits for $\bar{X}'$, σ', and p'): The sample is a random sample.

The 95 per cent confidence limits for $\bar{X}'$, σ', and p', on the basis of the 10 observed values given above, are as follows:

For $\bar{X}'$: $\bar{X} \pm a\sigma$ = 10,120 and 11,080 lb.
For σ': $k_1\sigma$ and $k_2\sigma$ = 460 and 1220 lb.
For p': p_1 and p_2 = 2 per cent and 56 per cent below 10,000 lb.

When each statement alone has a probability of 0.95 of being correct, it should be noted that the probability of all three statements being correct simultaneously is between $(0.95)^3 = 0.86$ and $(0.95)^2 = 0.90$, since p is not completely independent of $\bar{X}$ and σ.

NOTE.—The factor $a = \dfrac{t}{\sqrt{n-1}}$ is given on p. 43 of the ASTM "Manual on Quality Control of Materials" (**4**). The factor $k_1 = \dfrac{\sqrt{n}}{\sqrt{\chi^2_{0.025}}}$ and $k_2 = \dfrac{\sqrt{n}}{\sqrt{\chi^2_{0.975}}}$. Values of χ^2 may be found in

Table C, p. 613, of Duncan (18). (The value of n in Table C is $n - 1$.) Confidence limits for $\overline{X}'$ and σ' may be computed from R instead of σ, using factors in Table E1, p. 614, of Duncan (18), for limits for $\overline{X}'$, and factors in Table D on the same page for limits for σ'.

Values of p_1 and p_2 may be read from the chart given by Duncan on p. 350 (18) or read from tables of the binomial distribution as described on pp. 349–350. When pn is large (say, $pn > 4$), confidence limits for p' may be found from the equation:

$$p \pm t\sqrt{\frac{p(1-p)}{n}}$$

where $t = 1.96$, the Normal deviate, for 95 per cent limits.

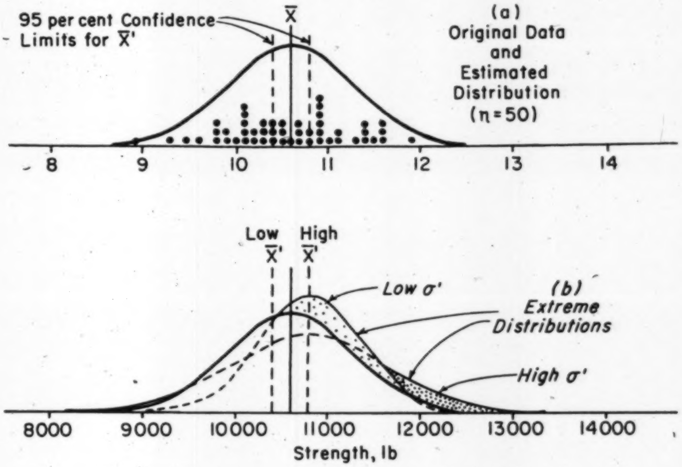


FIG. 19.—Effect of Errors of Estimation—Sample Size, $n = 50$.

Figure 18(a) shows the original data for the sample of 10, a Normal distribution with an average and standard deviation equal to the unbiased estimates of $\overline{X}'$ and σ', and also the 95 per cent confidence limits for $\overline{X}'$. From this it is apparent that confidence limits are rather wide. To indicate how uncertain the results really are for a sample of 10, another figure has been drawn, Fig. 18(b), that shows two extreme (Normal) distributions, both having an average corresponding to the higher confidence limit for $\overline{X}'$, one having a low σ' and the other a high σ' corresponding to lower and upper 95 per cent confidence limit values of σ'. Another pair of extreme distributions could be drawn for "low $\overline{X}'$." We would like to think that the true distribution looks like that given in Fig. 18(a) and reproduced in Fig. 18(b), but it might be as wide of the mark as either of the two extreme distributions shown in Fig. 18(b) (for the assumed conditions of 95 per cent confidence limits and Normal distribution).

NOTE.—The confidence limits for p' given above are based on the binomial distribution and are slightly wider than would be derived from the charts that assume that the underlying distribution is Normal.

This example and diagram may help to show that we can hardly expect to estimate universe parameters or distributions at all closely with a sample as small as 10. In any practical case, the question would be whether the confidence limits provide information sufficiently precise for the problem at hand. For many situations, the extreme range of possible distributions shown in Fig. 18(*b*) would be considered so great as to be of little practical usefulness. When this is so, the trouble may usually be assumed to be one of insufficient data.

The intervals can of course be shortened by taking a larger sample. For a sample of 50, the 95 per cent confidence limits are:

For $\overline{X}'$: 10,400 and 10,800 lb.
For σ': 570 and 850 lb.
For p': 9 and 31 per cent below 10,000 lb.

Figure 19(*a*) shows data for a sample of 50, so chosen as to have the same distribution as that in Fig. 18(*a*), and also shows the 95 per cent confidence limits for $\overline{X}'$ based on the 50 observed values. In turn, Fig. 19(*b*) shows two extreme distributions (similar to those of Fig. 18(*b*)), both having an average corresponding to the higher confidence limit for $\overline{X}'$, one having a low σ' and the other a high σ' corresponding to lower and upper 95 per cent confidence limit values of σ' (all based on a sample of 50). We see at once that with a reasonably large sample we can draw conclusions regarding the universe distribution to within quite moderate limits of variation. In fact, the square-root rule is applicable (approximately) for each parameter: Increase the sample fourfold to decrease the interval by half.

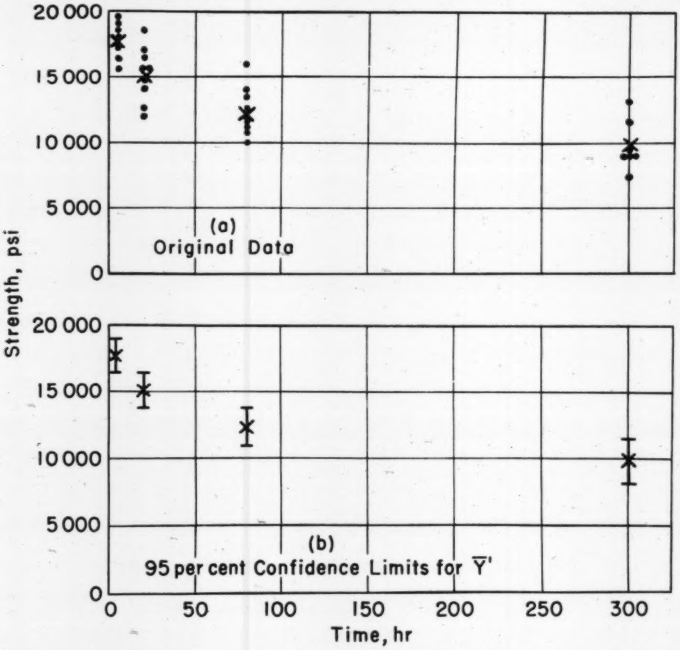


FIG. 20.—Relationship Between Two Variables; Confidence Limits at Fixed Values of *X*.

These examples have had specific reference to estimates of parameters, particularly $\overline{X}'$ and σ', and have not been

TABLE IV.—COMPUTED CONFIDENCE LIMITS FOR $\overline{Y}'$.

X, hr	Average, $\overline{Y}$, psi	Standard Deviation, σ	Number of Heats, n	95 Per cent Confidence Limits for $\overline{Y}'$
5.....	17 710	1330	7	16 380 to 19 040
20.....	15 100	1880	10	13 680 to 16 520
80.....	12 330	1800	9	10 860 to 13 800
300.....	9 770	1700	7	8 070 to 11 470

intended to provide useful information regarding the *shape* of distributions. Using the Normal distribution for illustrative purposes has been merely an aid in providing a visual comparison of relative spreads of distributions.

Estimates of Regression of Y on X:

Many ASTM studies are made for the purpose of finding the relationship between two variables. Often the values of one variable, X, are fixed at set intervals, and several values of the other variable, Y, are measured for each fixed value of X. Figure 20(a) shows some data of this kind,[8] used here only as an illustration of a method of estimating the relationship between two variables.

The values of X in Fig. 20(a) are values of total deformation time in hours (5, 20, 80, and 300), while the values of Y are values of 1.0 per cent total deformation strength, in psi, for type 321 sheet alloy at 1350 F. Hereafter we shall refer to X as time and Y as strength.

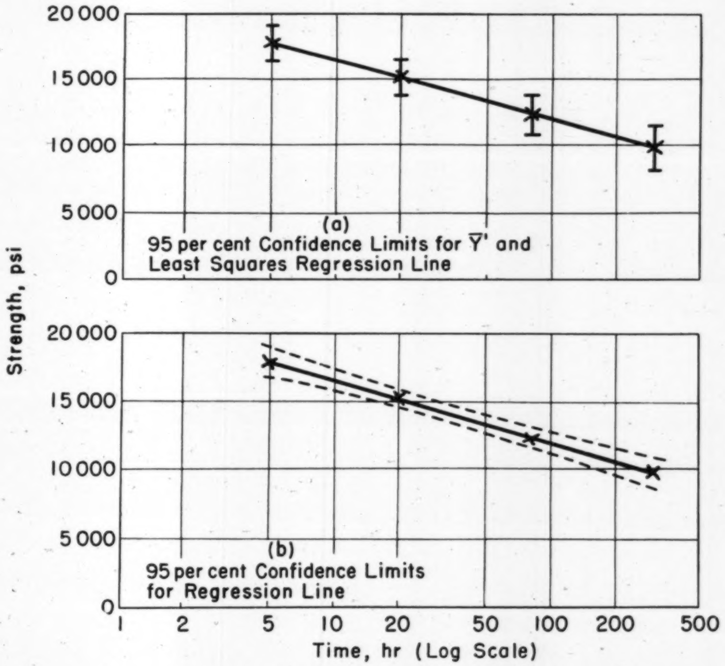


FIG. 21.—Improvement (Narrower Band Around the Regression Line in (b)) That Results When the Assumptions for Placing Confidence Limits on the Regression Line Itself Are Satisfied.

For each sample of Y values corresponding to the four values of X, the individual Y values (one value for each of seven to ten heats) are plotted as dots; each $\bar{Y}$ value (average) is designated by a cross. For each of these samples of Y values, the values of $\bar{Y}$, σ, and 95 per cent confidence limits for $\bar{Y}'$ were computed as shown in Table IV. The confidence limits are of the form $\bar{Y} \pm a\sigma$, as described under Interval Estimates, and they are interpreted in the same way.

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[8] From A. I. Rush and J. W. Freeman, "Statistical Evaluation of the Creep-Rupture Properties of Four Heat-Resistant Alloys in Sheet Form," see p. 1098 of this publication. The authors did not present the data in this way.

If there is a true functional relationship between X and Y', it may be regarded as the locus of the $\bar{Y}'$ points corresponding to the X values. Therefore, the line or curve is likely to fall within the confidence limits. The values of $\bar{Y}$ and the 95 per cent confidence limits are shown in Fig. 20(*b*).

The shape of the curve suggests using log X as the abscissa so that the values will be more evenly spaced. Figure 21(*a*) shows the values of $\bar{Y}$ and the confidence limits for $\bar{Y}'$ plotted against X on a log scale, as well as a least squares straight line fitted to the data. This looks like a good fit. If there is good reason to believe that the true functional relationship is a straight line using this scale, and if the distributions of Y (corresponding to the four values of X) have about the same spread, this line based on all the data collectively gives estimates of $\bar{Y}'$ corresponding to values of X throughout the range of X values, rather than at four isolated points. This line, joining these estimates of $\bar{Y}'$, is called the "regression line of Y on X," and it is possible to compute (**19**, pp. 540–546) confidence limits for the regression line which are considerably *narrower* than the confidence limits shown in Fig. 21(*a*).

NOTE.—These limits are of the form:

$$Y_i \pm t_\alpha s \sqrt{\frac{1}{\Sigma n_i} + \frac{(X_i - \bar{X})^2}{\Sigma n_i (X_i - \bar{X})^2}}$$

where:

$\alpha = 1 - 0.95 = 0.05,$

$s = \sqrt{\dfrac{\Sigma\Sigma(Y_{ij} - Y_i)^2}{(\Sigma n_i) - 2}},$

n_i = number of Y values corresponding to X_i,

$Y_i = a + bX_i$, and

$Y_i = 20{,}883 - 4484 (\log X_i)$ for this example since values of X were transformed to log X to fit a straight line to the data.

t may be found in Table B, p. 612, of Duncan (**18**) (using $\Sigma n_i - 2$ for "n" in Table B).

Figure 21(*b*) shows the least squares regression line fitted to the data and the 95 per cent confidence limits for the regression line. The reason the confidence limits are wider at the ends is that our knowledge of the regression line is less precise at the ends than in the middle. The statement, "The true relationship between strength and time lies within these limits," has 95 chances in 100 of being correct if:

(*a*) the distribution of Y for each universe (corresponding to each value of X) is approximately Normal,

(*b*) the sample is a random sample,

(*c*) the variances of the different universes of Y are the same, and

(*d*) the true relationship is a straight line for the scales used.

If, then, the engineer has this added knowledge regarding the mathematical form of the true relationship (and it should be knowledge, not wishful thinking), and if, in addition, through statistical tests, he satisfies himself on item (*c*) above, then he can use the narrowed confidence limits for the regression line (Fig. 21(*b*)). What he has done is to make use of a particular mathematical model that has some rather stringent limitations—straight line, constant variability, etc. In his use of this model, he must remember that he needs to justify his choice of model—to give evidence or other information that may be considered sufficient grounds. Otherwise the critical reader may have but a very small degree of belief, p_b, in the presentation. Lacking adequate grounds for using the confidence limits of Fig. 21(*b*), he can use the less precise presentation of Fig. 21(*a*) or even Fig. 20(*b*), subject of course to the limitations that apply to each of the several sample sets of observations (items (*a*) and (*b*) of the section above on Interval Estimates).

CONTROL CHART METHOD OF CONTROLLING QUALITY

Some General Principles:

Too often, perhaps, a single sample, large or small, will be taken from the output of some manufacturing process, confidence limits computed for the average and the dispersion, and the results taken to indicate not merely what the quality of the product *was* at the time when the sample was taken but *also* what the quality *will be* in the future.

This assumes that the process is a stable one, that a particular frequency distribution is associated with a particular manufacturing process and remains essentially unchanged as time goes on. In other words it assumes that the process is in a state of statistical control. The assumption is an easy one, a particularly convenient one to make when data are limited and there is no evidence at hand that can contradict it. The only trouble with it is that it usually is not true. Many processes may remain reasonably stable for short periods of time, but more often than not there are trends or sudden shifts in the process levels that can persist for substantial periods of time, unless engineering or production forces have set up a system of purposive process controls to detect and eliminate assignable causes as soon as they appear.

When the end product is the composite output of multiple sources—several like machines, several assembly groups, several operators performing like functions, etc.—process controls can often be placed most advantageously at each of these separate sources, to keep the subportions of output close to a common standard and prevent the wider variability in quality that results from the merging of several streams that have not been directed toward a common target or "aimed-at" value. Many examples in the field of quality control—multihead machine operations, soldering, clerical recording and tabulating, etc.—illustrate the fact that with multiple sources the most frequent cause of trouble at any one time is one of the several production sources, and that systematic detection of such causes, as by a control-chart procedure applied to the separate sources, is a most effective way of improving quality.

Example—Process Quality Control:

The effect of introducing a control-chart method of controlling quality during production is illustrated by an example that dates back to the early days of World War II. The procedure followed was essentially that given in American War Standard Z1.3, "Control Chart Method of Controlling Quality During Production" (6). This particular example relates to the control of weight of powder charge in a certain type of 30-caliber ammunition in one of our arsenals.

In this particular plant there were over seventy machines all going through essentially the same operation of adding a charge of powder to a cartridge case. The quality of output was subject to measurement checks by several inspectors—one inspector normally watched over several machines. Before instituting a control-chart plan on the machines, each inspector made frequent individual checks of charge weight for her particular machines and indicated when, from the results of her check weighing, a particular machine appeared to require adjustment in order to modify the weight of charge.

The control-chart plan, applied separately to each machine, called for:

(*a*) selecting at random a sample of 5 units every hour (later every 2 hr) during the three shifts,

(*b*) weighing the charge in each of the 5 sample units, (*c*) computing the average, $\bar{X}$, and the range, R, of the 5 values,

(*d*) plotting promptly the average and range on a large chart that accommodated results for seven successive days, and

(*e*) taking corrective action when and only when a sample average or a sample range fell outside the control limits of the chart.

At the outset, preliminary data (samples of 5) were obtained for each machine to find a value of average range, $\bar{R}$, for that machine, which would represent the inherent variability of the process for that particular machine and would provide values needed for computing control limits for X and R.

The goal in this operation was to maintain charge weights at a desired nominal value, the nominal value being specific to each individual lot of powder being used. Thus the control limits were (**4**, p. 62):

For $\bar{X}$: upper control limit (UCL) = nominal $+ A_2\bar{R}$ = nominal $+ 0.577\bar{R}$.

For $\bar{X}$: lower control limit (LCL) = nominal $- A_2\bar{R}$ = nominal $- 0.577\bar{R}$.

For R: upper control limit (UCL) = $D_4\bar{R}$ $= 2.115\bar{R}$.

As the plan went into effect, instances of lack of control were encountered by an $\bar{X}$ or an R falling outside the control limits (see Fig. 22). This meant stopping the machine and taking corrective action. For $\bar{X}$ out of control, corrective action consisted of an adjustment to increase or to decrease the weight of filling. This apparently often happened for the first sample on a Monday morning. For R out of control, the corrective action often consisted of cleaning out the charging block or blowing it out with compressed air.

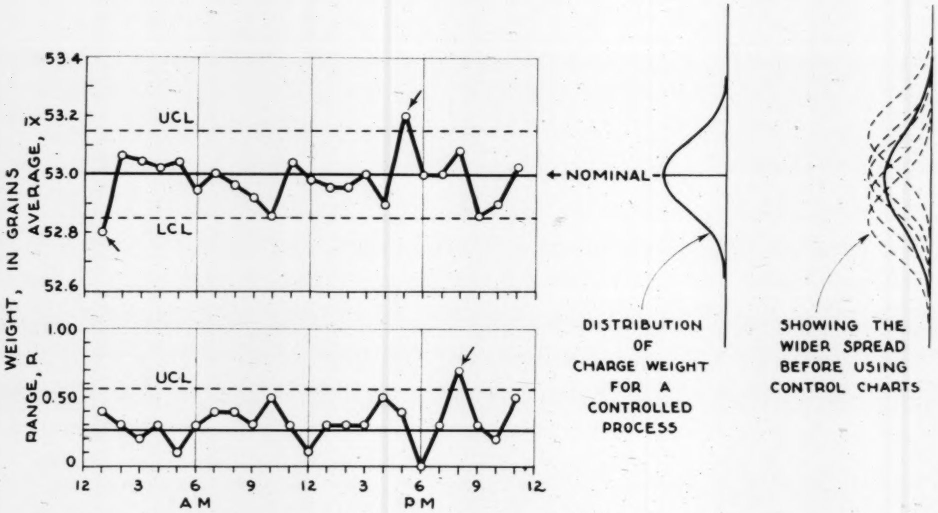

FIG. 22.—$\bar{X}$ and R Control Charts for Weight of Powder Charge, with Distributions Before and After Control.

But the surprising thing was there were now fewer adjustments than before the control charts were installed, and the machine down-time was considerably reduced. Some machines ran for much longer periods without adjustment than had been experienced in the past. An analysis of the over-all quality of the output, made some time after the plan had been in effect, gave the most significant result of all: the over-all quality was better than before and was more uniform. That is, the spread above and below the nominal or "aimed-at" value was definitely smaller than before. Here was better quality, less machine down-time, more production, less cost. How could this be explained?

What happened is not known precisely, but it appears to have been something like this. Before the control-chart method was introduced, the inspector normally made a single check measurement in each of her inspections of a machine. The criterion for action (when to adjust a machine and when to let it alone) was not designed to take account of individual machine variability, and in the interests of producing the very best quality for the armed forces, the inspector undoubtedly called for adjustments on occasions when none was needed—when the evidence used in deciding to adjust was a single moderately high or low reading. The effect of making an adjustment when none was needed was to *introduce variation* by shifting the average of the *universe* distribution. If this were done regularly, the effect would be to give a widened spread as shown by the series of dotted distributions at the right of Fig. 22. This is apparently what had been going on unknowingly.

This example helps to illustrate one or two important points. First, when the control chart is used to control quality during production, not only does it tell when to take action but, equally important, it tells when to let the process alone. Second, the control chart, in providing a consistent rule for action, not only saves an individual from that onerous job of making decisions, but it may improve the uniformity of quality by preventing the introduction of variations caused by over-zealous tinkering with a well-designed process.

HOW LARGE A SAMPLE

A General Problem:

Another type of problem that comes up frequently has to do with determining how large a sample[9] should be taken for some particular purpose. Usually, quantitative results are wanted which will be subject to an interpretation that will serve as a useful basis for making some decision or taking some action. Statistical methods provide a suitable probability model for solving this problem, using a language that the practical man has no difficulty in understanding. A clear and illuminating discussion of such models and the relation between the symbolic world and the real world in statistical problems is given by Irwin D. J. Bross in his book, "Design for Decision" (17).[10]

Example—Quality Measured by the Method of Attributes:

This example, drawn from experience, relates to the problem of sample size for a product characteristic whose quality is measured by the method of attributes, in per cent defective.

A has a stock of 50,000 units of apparatus (let us call them capacitors), suspects that an appreciable percentage of the units are defective for a particular test feature, and wishes to sample the stock to find out how bad they really are. *A* goes to *B*, a quality assurance engineer, explains the situation, and then asks: "How large a sample shall I take?"

This is a problem in estimation. It is not a routine problem but, rather, a special one. *A* must supply certain information if his question is to be answered. Much depends on just what it is that *A* wants. The solution generally goes something like this:

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[9] This problem is under study by a Task Group, headed by A. G. Scroggie, of ASTM Committee E-11 on Quality Control of Materials.

[10] See especially Chapter 10. This book, written in everyday language, is particularly recommended for engineers.

B asks: How bad do you think the quality is?

A answers: I don't know. That's what I want to find out.

B: Do you think it's about 5 per cent defective?

A: Oh, it's worse than that.

B: 20 per cent defective?

A: Not as bad as that.

B: 10 per cent defective?

A: Yes, maybe about 10 per cent defective.

(*B* writes down on a piece of paper, $p' = 0.10$, meaning that he is going to assume that the lot fraction defective is 0.10, for the purposes at hand. Then he goes on with his questions.)

B: How close do you want to know the per cent defective?

A: I don't know. I just want to know what it is.

B: Do you want to know it to within ±0.1 per cent?

A bristles and says: Don't be silly!

B: To within ±5 per cent?

A: Of course not! I want to be closer than that!

B: To within $\pm\frac{1}{2}$ per cent?

A: Yes. That's about right.

(This gives an error of $p = 0.005$. *B* therefore writes down: $E = 0.005$.)

B: Now, how sure do you want to be that the error won't exceed $\frac{1}{2}$ per cent?

A: Now listen! I've given you all sorts of figures that I've had no business to. I just want to be sure that the error won't be greater than $\frac{1}{2}$ per cent.

B: Do you mean something like chances of 999 in 1000?

A bristles again, and says: Don't be silly!

B: Chances of 50 in 100?

A: No, no!! I want to be surer than that.

B: How about chances of 9 in 10?

A: O.K. That's about right.

(In isolated problems such as this, engineers often choose 9 in 10. This gives a probability of 0.90. Using a Normal Law probability function, which is suitable in the present case, a value of $t = 1.65$ results. Probability values of 0.95 and 0.99 are more commonly used in recurring statistical problems. Values of t are as follows:

Probability	t
0.90	1.65
0.95	1.96
0.99	2.33

B now substitutes the values $p' = 0.10$, $E = 0.005$, and $t = 1.65$ in the following equation for sample size n:

$$n = \frac{t^2}{E^2}(p')(1 - p')$$

$$= \frac{(1.65)^2}{(0.005)^2}(0.10)(0.90) = 9800$$

B: Here's the answer—a sample of 9800.

A: Wa-a-i-t a minute! That's ridiculous. I can't take a sample that big.

B: Well, then, how about allowing a little larger error?

A: Like what?

B: Say an error of 1 per cent instead of $\frac{1}{2}$ per cent?

A: What'll that give me?

B: For an error of 1 per cent, the sample will be 2450.

$$n = \frac{(1.65)^2}{(0.01)^2}(0.10)(0.90) = 2450$$

A: That's more like it. In fact, that looks quite reasonable.

Since this order of magnitude looks satisfactory to *A*, the final step is in the nature of a refinement, to take into account the lot size, N. The formula used above was for estimating the p' of unlimited universe (a process, or a lot of infinite size). The correct sample size for a limited universe, n_L, bears the following simple relation (approximate) to the sample size for an unlimited universe, n:

$$n_L = \left(\frac{N}{N + n}\right) n$$

Substituting $N = 50{,}000$ and $n = 2450$ gives $n_L = 2340$ as the required sample size.

Now, except perhaps for advice on methods of distributing the sample over various portions of the stock in order to disclose possible concentrations of trouble, *A*'s problem is solved. What has been the approach?

First of all, *B* needed to find out exactly what *A* wanted to do, namely, to estimate the per cent defective in a large quantity of product that was actually available for sampling. From this information, *B* chose as a mathematical model the distribution of sampling errors for random samples drawn from a given binomial universe.

Second, *B* had to get from *A* some idea of the degree of defectiveness of the material to be sampled. Often in practice one meets the contention that nothing—absolutely nothing—is known regarding the quality of the subject-lot of material or process. Seldom is this really so. Someone is available who knows something about it—who knows recent history, current conditions, and other factors that give at least the general order of magnitude of the quality under consideration. At the very least, if he is asked the right kind of questions, he can narrow the band down to a sufficient degree for the purpose at hand.

Finally, *B* had to find out what precision of result was wanted by *A* and what risk of error he could stand. When his first choice of constants gave a sample size that looked unreasonable (too costly) to him *for what he had in mind*, he was willing to allow a greater error in order to get a sample size that satisfied his own personal criterion of reasonableness. And that is the basis for many solutions of sample size. He who is paying the bill weighs the value of greater precision *versus* the cost and comes down to some sample value that seems to strike a proper balance between value and cost. This is a personal decision. The mathematical model provides a basis for understanding; it gives a yardstick for measuring how good an answer can be expected for any given choice of constants.

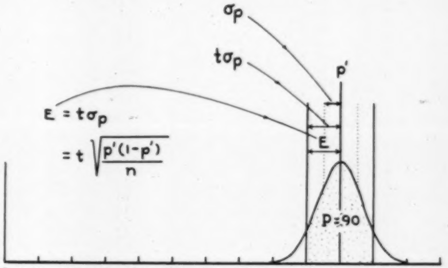

FIG 23.—Model Used for Finding Sample Size, *n*.

The model used in this problem can be visualized from the diagram in Fig. 23. We take *A*'s guess of $p' = 0.10$ (10 per cent defective) as the assumed universe from which a sample is to be drawn. Values of fraction defective, p, in random samples of size n, drawn from an unlimited universe having a fraction defective p', will be distributed around p' with a standard deviation of

$$\sigma_p = \sqrt{\frac{p'(1-p')}{n}}$$

(for a limited universe of N units,

$$\sigma_p = \sqrt{\frac{p'(1-p')}{n}} \quad \sqrt{1 - \frac{n}{N}}\ ).$$

For n large enough that np' is greater than, say, 4 or 5 (as is true in this case), this distribution can for most practical purposes be considered to be a Normal distribution. In the problem at hand, since the error is to be limited to 1 per cent (0.01) with a probability of 0.90, we merely have to find that value of n such that the distribution of sample values of p (Fig. 23) will have 90 per cent of its area within the band $p = 0.10 \pm 0.01$.

Some might contend that this solution

will not provide *A* with the solution he wants if p is sharply different from the estimated value of 0.10. Suppose *A* took his sample and found $p = 0.19$ (19 per cent defective). *A* had said he wanted an error of not more than 1 per cent (of course, for the specific conditions $p' = 0.10$ and probability = 0.90). Now with p' equal to about 19 per cent defective, his error (for probability = 0.90) might be as large as 1.3 per cent, which is greater than the 1 per cent agreed upon. Whether the contention mentioned above is valid or not appears to be a matter of *A*'s understanding at the outset. For example, with the problem as solved, when *A* agreed to a sample size of $n = 2340$ and an error of 1 per cent for $p' = 0.10$, he could be advised that this sample size would give an error of about 1.2 per cent if p' were 0.15 and about 1.3 per cent if p' were 0.20. If, before taking his sample, *A* had this complete understanding regarding what could be expected of a sample of 2340 and still agreed, then there would be no grounds for dissatisfaction with the sampling plan as a result of a difference between the actual p and the expected value, p'.

Quality Measured by the Method of Variables:

The same general procedure is followed if it is desired to determine, by sampling, the average value (arithmetic mean) of some measureable characteristic, X, for a given process (unlimited universe) or for some definite quantity of product (limited universe). Here the problem is to find out how large a sample, n (number of units or number of observations), is required to determine the average of the quality characteristic under consideration: (*a*) with some prescribed maximum error, E, for the sample average, $\bar{X}$, and (*b*) with a chosen value of probability.

To solve the problem, there must be provided some estimate of the standard deviation of individual measurements, σ', for the universe under consideration. This, together with chosen values of E and t, is used in the following formula for determining the sample size, n (number of units or number of observations) in sampling from an *unlimited* universe:

$$n = \frac{t^2\sigma'^2}{E^2}$$

where:

E = prescribed maximum error, expressed in the same units of measurement as the sample average, $\bar{X}$, and

t = a chosen constant for a given probability (as given on p. 32).

To find the sample size, n_L, in sampling from a *limited* universe of N units, the above formula is first used to find the sample size, n, in sampling from an unlimited universe, and the result is then corrected by a factor $\left(\frac{N}{N+n}\right)$, thus:

$$n_L = \left(\frac{N}{N+n}\right)n$$

In practice, most problems will call for the use of the formula for n, rather than the formula for n_L. If the sample is to provide information about the average of a process, the formula for n applies directly. If the sample is to provide information about the average of some definite quantity (lot, batch, shipment, etc.) of product, the formula n_L applies; however, the formula for n is generally used as an approximation if the ratio of sample size to lot size, n/N, is small—say, less than 0.05 or even 0.10. Furthermore, the formula for n can appropriately be applied to sampling from a limited universe when the lot is continuous in character in respect to the characteristic in question, that is, not naturally made up of discrete pieces that can be tested separately for that characteristic. In this case, the lot size, N, cannot be expressed in terms of a number of units but can for all practical purposes be considered as unlimited, while the sample size, n, is the number of test specimens that are selected for purposes of test. Examples include most physical properties of materials, such as tensile strength of strand, hardness of sheet brass, moisture content of vitrified clay conduit.

SUMMARY

In quality engineering and probably in many other kinds of engineering, statistical methods, particularly some of the simpler techniques used in quality control, are important in planning for the collection of data as well as in the interpretation of the data after they have been obtained.

Most engineering data on the quality of materials or manufactured products can be looked upon as samples—samples of information with respect to either (*a*) the product already made or (*b*) the underlying cause system behind the data, including all of the many factors of variation in both the production process and the measurement process. Much is to be gained by emphasis on the latter view. Knowledge of processes and knowledge of methods of measurement result from continuing attention to variations that do not conform to expected patterns. We can expect to improve our control over the various operations and processes that we employ in the laboratory and the factory and to attain most economical production if we use our engineering data to find and eliminate assignable causes of variation.

Statistical quality control is a goal that we may hold before us as an ideal. Once attained in any segment of endeavor, we are enabled to make valid predictions regarding the output of future operations. Statistical methods and quality control techniques provide a means for approaching this goal.

Acknowledgments:

I wish to acknowledge my gratefulness to many individual members of the American Society for Testing Materials for helpful comments and suggestions received during the preparation of this lecture. I wish particularly to express my appreciation to Miss Mary N. Torrey for technical contributions and assistance and to Miss Alice G. Loe for the preparation of the illustrations.

REFERENCES

(1) Harold L. Maxwell, "Chemical Developments and Engineering Materials," ASTM BULLETIN, No. 194, December, 1953, p. 47 (TP191).

(2) Walter A. Shewhart, "Economic Control of Quality of Manufactured Product," D. Van Nostrand Co., Inc., New York, N. Y. (1931).

(3) Eugene L. Grant, "Statistical Quality Control," McGraw-Hill Book Co., Inc., New York, N. Y. (1952).

(4) Manual on Quality Control of Materials, Am. Soc. Testing Mats. (1951). (Issued as separate publication *ASTM STP No. 15-C.*)

(5) A.S.A. War Standards Z1.1 and Z1.2, "Guide for Quality Control" and "Control Chart Method of Analyzing Data," Am. Standards Assn., New York, N. Y., May, 1941.

(6) A.S.A. War Standard Z1.3, "Control Chart Method of Controlling Quality During Production," Am. Standards Assn., New York, N. Y., April, 1942.

(7) H. F. Dodge and Harry G. Romig, "Sampling Inspection Tables, Single and Double Sampling," John Wiley and Sons, Inc., New York, N. Y. (1944).

(8) H. F. Dodge, "Acceptance-Rejection Requirements in Specifications," *Proceedings*, Am. Soc. Testing Mats., Vol. 34, Part II, p. 877, Fig. 1 (1934).

(9) I. W. Burr, "Analysis and Correlation of Data" (1952 Education Series of the Philadelphia Chapter, Am. Soc. Metals), *Metal Progress*, October, 1953, p. 112. Example taken from the fourth lecture of the Philadelphia Chapter series by John W. W. Sullivan: Jominy end-quench tests for 331 heats of 4032H steel; Rockwell C-scale hardness $\frac{1}{16}$ in. from the quenched end.

(10) Walter A. Shewhart, "Statistical Method from the Viewpoint of Quality Control," The Graduate School, The Department of Agriculture, Washington, D. C. (1939). Edited by W. Edwards Deming.

(11) H. F. Dodge, "Statistical Control in Sampling Inspection," *American Machinist*, Vol. 76, October 26, 1932, pp. 1085–1088.

(12) W. Edwards Deming, "On the Distinction Between Enumerative and Analytic Surveys," *Journal*, Am. Statistical Assn., Vol. 48, pp. 244–255 (1953). For a more complete treatment of the subject under discussion, see reference **13**, Chapters 7 and 8.

(13) W. Edwards Deming, "Some Theory of Sampling," John Wiley and Sons, Inc., New York, N. Y. (1950).

(14) Walter A. Shewhart, "Statistical Control in the Conservation and Utilization of Resources," U. N. Conference on Conservation and Utilization of Resources, *Proceedings of the U. N.*, Vol. 1, August 17–September 6, 1949.

(15) D. J. Finney, "Probit Analysis," Cambridge University Press, p. 233 (1952).

(16) Paul S. Olmstead, "QC Concepts Useful in OR," *Quality Control Convention Papers, 1954*, Am. Soc. Quality Control, New York, N. Y., June, 1954.

(17) Irwin D. J. Bross, "Design for Decision," The MacMillan Co., New York, N. Y. (1953).

(18) A. J. Duncan, "Quality Control and Industrial Statistics," Richard D. Irwin, Inc., Homewood, Ill. (1952).

(19) A. Hald, "Statistical Theory with Engineering Applications," John Wiley and Sons, Inc., New York, N. Y. (1952).

GILLETT MEMORIAL LECTURE

THE GILLETT MEMORIAL LECTURE is sponsored jointly by the American Society for Testing Materials and Battelle Memorial Institute in commemoration of Horace W. Gillett, the subjects of the Lectures to pertain to the development, testing, evaluation, and application of metals.

FATIGUE OF ALUMINUM[1]

THIRD GILLETT MEMORIAL LECTURE

By R. L. Templin[2]

Mr. F. M. Howell, Chief, Mechanical Testing Division, Aluminum Company of America, assisted in the preparation of the lecture and also, due to the protracted illness of Mr. Templin, made the presentation.—Ed.

This is the third occasion on which we have gathered for the purpose of suitably recognizing the achievements and memory of one of America's most noted metallurgists, Dr. Horace W. Gillett. Both the Battelle Memorial Institute and the American Society for Testing Materials have agreed that an annual lecture dealing with the development, testing, evaluation, or application of metals would constitute an appropriate memorial to this great man, who has been respectfully referred to as "this Grand Old Man of American Metallurgy," and as the "Maker of Men and Metals."

The person selected to give the initial Horace W. Gillett Lecture was Norman L. Mochel. The outstanding job done by him is apparent to all who heard or have read his lecture, which was presented before the Fiftieth Anniversary Meeting of this Society in 1952, under the title of "Man, Metals, and Power."[3]

The second Gillett Memorial Lecture, "Micrometallurgy—The Metallurgy of Minute Additions,"[4] presented before the Society last year by Jerome Strauss, was again a notable and worthy tribute to the memory and interests of his old friend, Dr. Gillett.

The previous lecturers have given such a comprehensive description of the man honored, his life, his works, his technical interests and achievements, his hobbies and amusements, that little if any remains that can be added. It was my privilege to have known Dr. Gillett throughout many years—when he was active on ASTM committees, while at the National Bureau of Standards, and throughout his work at Battelle Memorial Institute. We had a kindred interest in outdoor sports and invariably gave up part of our conversational time to quail or grouse shooting. Having attained our bag limit of birds, Gil would pop the familiar question, "What's new?" The answer to this question nearly always involved aluminum, a subject in which his interest antedated mine by at least a decade. In the list of publications of H. W. Gillett may be found numerous papers concerned with aluminum. The first of these appears to have been presented in 1911, and the papers extend from that time throughout the rest of his life. In my contacts with him, he led me to believe that he was particularly interested in the fatigue properties of aluminum and its alloys, and, by one means or another, he managed to keep himself reasonably familiar with the work on this subject which I initiated in the laboratories of the Aluminum Company of America in 1919, and which has been continued and appreciably expanded in these laboratories since that time. On two or three specific occasions, he strongly suggested that, and gave reasons why, this investigational work should be further amplified and the results obtained suitably publicized. Some of the results from this earlier work on the fatigue properties of aluminum were presented to this Society 20 years ago, and Dr. Gillett's suggestion was among the factors influencing the writing of that paper (**55**).[5] Since that time, other papers covering specific phases of the fatigue properties of aluminum and its alloys, as evaluated by Alcoa's laboratories, have been presented to this and other technical societies (**59, 78, 87, 102, 108, 109, 110, 130, 131, 139, 140, 145, 146, 152, 153, 156, 161, 173, 180, 195, 209, 222, 228, 236, 257, 258, 287, 306, 308, 325, 336, 337, 388, 397, 412, 416, 417, 418, 419, 454, 462, 481, 486, 487, 488, 494**). On this occasion, an attempt will be made to summarize the knowledge of the subject, without restriction as to source, toward the end that the useful lives of aluminum-alloy structures and machines subjected to repeated loads in service may be extended.

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[1] Presented at the Fifty-seventh Annual Meeting of the Society, June 15, 1954, Chicago, Ill.

[2] Assistant Director of Research and Chief Engineer of Tests, Aluminum Company of America, New Kensington, Pa.

[3] *Proceedings*, Am. Soc. Testing Mats., Vol. 52, p. 691 (1952).

[4] *Proceedings*, Am. Soc. Testing Mats., Vol. 53, p. 577 (1953).

BRIEF DESCRIPTION OF FATIGUE PHENOMENA

The nature of fatigue phenomena in metals has been discussed extensively in the technical literature by many engineers and scientists over the past 100 years. The review presented by Peterson (**298**) in the February, 1950, ASTM BULLETIN is particularly noteworthy. It will be assumed, for the purposes of this lecture, that those interested in the subject are reasonably familiar with the general behavior of materials subjected to repeated loading conditions. Under such conditions, failures can occur that are often characterized as being of the brittle type. In most instances, the computed nominal stresses are within the elastic ranges of the materials. Frequently the fatigue cracks can be associated with geometric configurations, surface conditions, or internal structure characteristics, all of which are recognized as stress raisers. While these factors have deleterious effects on the fatigue properties of all metals, the quantitative significance of each may vary, depending on the particular material and the conditions of service. Aluminum alloys generally behave like other commonly used metals when subjected to repeated stresses. Such significant differences as are now known to exist between the behavior of the aluminum alloys and other metals will be pointed out in the course of this lecture.

FUNDAMENTAL MECHANISM OF FATIGUE FAILURES

The increasing efforts by engineers to use metals more efficiently in machines and structures subjected to repeated loads have resulted in more fatigue failures in service. These failures, in turn, have served to intensify the interest in the nature of fatigue and the desire to understand the fundamentals of its mechanism. Such knowledge undoubtedly would be helpful in effecting improvements in the fatigue properties of metals. Of the many useful contributions made toward realization of such understanding, those by Ewing and Rosenhain, Ewing and Humphrey, Gough and coworkers, Hansen and Wheeler, Orowan,

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[5] The boldface numbers in parentheses refer to the bibliography appended to this paper, see p. 679.

Moore, and Forsyth are particularly noteworthy (**1, 2, 21, 39, 53, 80, 106, 264, 440, 441**), but this list by no means contains the names of all those who have made helpful contributions. Progress toward obtaining entirely satisfactory answers to the many questions arising has indeed been slow, when we realize that the fatigue problem was first recognized more than a century ago.

Recent work by Hunter and Fricke (**488**) shows some interesting facts concerning the behavior of aluminum alloys under repeated stress from a very few cycles to final failure of the material, at various stress levels. They have observed minute structural changes occurring early in fatigue tests, as shown in Fig. 1, and have developed techniques whereby the progress of a fatigue crack in an aluminum alloy subjected to repeated stressing is followed essentially from beginning to end.

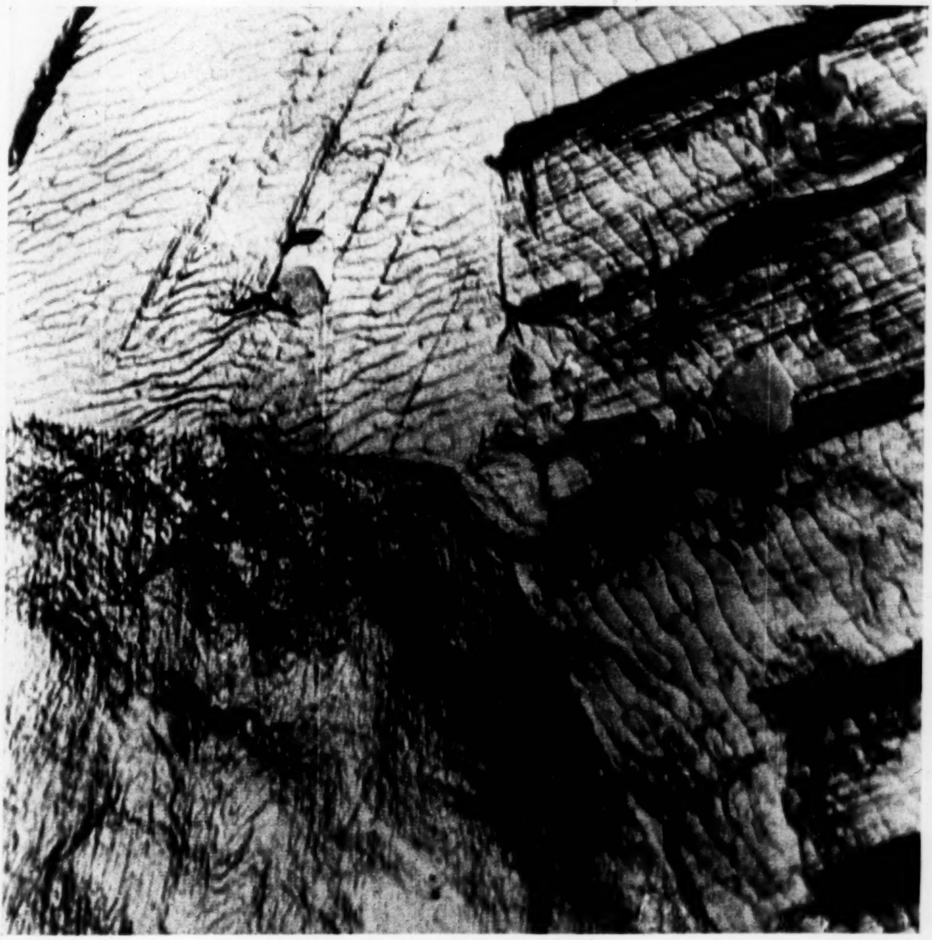


FIG. 1.—Oxide Film Replica Showing Several Stages of Structural Change Resulting from Fatigue Action as Revealed by Electron Microscopy (× 25,000) reduced to ¾ size in reproduction.

It would appear from their work to date that in the case of aluminum alloys, at or above a specific stress level for each material, minute fissures first develop along slip planes in those grains having certain orientations. Concentration of dislocations on the most highly stressed slip planes of these grains probably weakens those planes and leads to the formation of the fissures. With repeated stressing, these fissures eventually join to form more nearly continuous cracks on these planes. As repeated stressing continues, the cracks join or connect with similar cracks on neighboring parallel slip planes within the same grain. This stage represents the microstructural conditions frequently found by the usual microscopic examination. Upon further repeated stressing, some of these cracks join with similar cracks in adjacent grains. This constitutes the beginning of the ultimate catastrophic fatigue failure of the material. Correlation of what Hunter and Fricke have termed "first crack" with the final fatigue failure of the material appears to offer some promise as a means for estimating the number of cycles to ultimate failure of the material, if the stress level is known. These workers have found no evidence of incipient cracks below certain limiting stress levels, varying with the different materials, and these stress levels seem to be slightly below the nominal endurance limits of the materials. Investigation by their associates has revealed a subgrain structure of submicroscopic size which has only recently been recognized. This structure may have an influence on fatigue behavior, although its significance is not yet fully understood.

As is characteristic of such research effort, many new questions have arisen during the course of the work, necessitating considerable additional effort before suitable answers can be obtained. Similar investigations are currently under way by other investigators, involving aluminum and other metals. It would therefore seem reasonable to hope for a much better understanding of the fundamentals of the fatigue mechanism when the results of the work now in progress become available. Both the optical and the electron microscopes have been very helpful in this basic research work.

Much research effort has been expended, and is continuing, in attempting to improve the fatigue strengths of aluminum alloys. So far, this work has not resulted in any outstanding increases in the fatigue strengths of these alloys. The aluminum powder metallurgy products at high temperatures are a notable exception. These alloys exhibit better fatigue properties than any previously obtained for temperatures from 600 to 800 F.

EVALUATION OF THE FATIGUE PROPERTIES

It appears that the earliest fatigue tests of aluminum reported in the technical literature were those described in the *Proceedings* of this Society by Souther in 1907 (3). He gave rotating-beam, smooth specimen fatigue data for a number of aluminum-base casting alloys, among which was the widely used aluminum alloy containing about 8 per cent of copper. In passing, it is interesting to note that the fatigue strength values that he obtained for these aluminum alloys are in excellent agreement with similar fatigue strength values obtained recently.

It is of further interest to note in the discussion that followed the presentation of this paper that Mr. Gaetano Lanza made the following remarks:

> "I believe that before long we shall have to prescribe, in many cases, specifications for endurance tests; moreover, I will add that in Committee K [Standard Methods of Testing—now Committee E-1] we have arranged to have a subcommittee on endurance tests. While this subcommittee has not

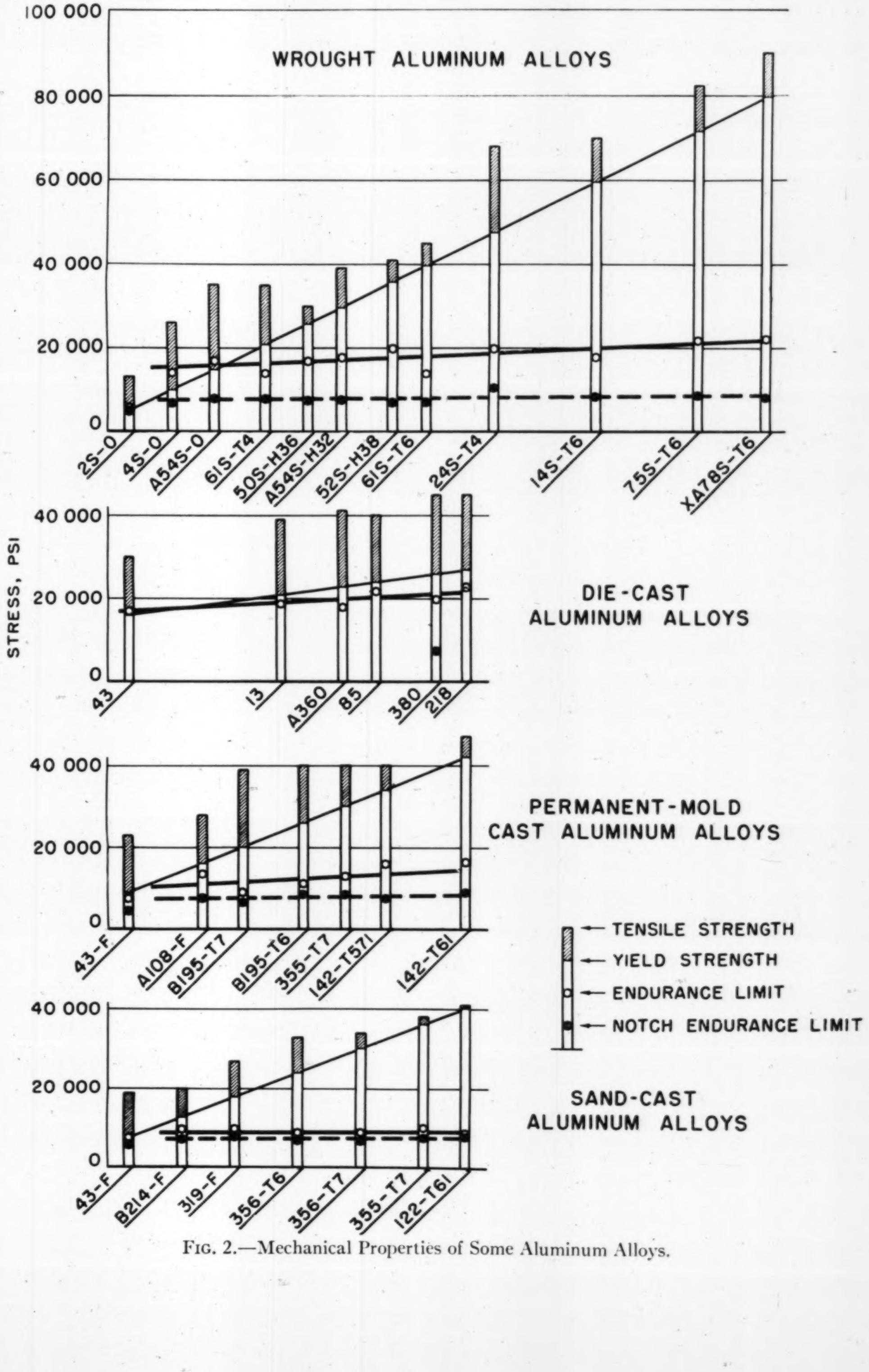


FIG. 2.—Mechanical Properties of Some Aluminum Alloys.

yet been set to work, nevertheless requests have already been sent by Committee K to the various testing laboratories, asking for a statement of their practice in this regard, the replies to serve as an aid to the subcommittee in its work."

These remarks suggest the beginning of our Society's present Committee E-9 on fatigue.

Evidence of the interest in the fatigue properties of aluminum-base alloys in England first appears in the Ninth Report to the Alloys Research Committee, January, 1910 (**4**). The data given are ascribed to T. E. Stanton and pertain to two aluminum-base alloys, in the cast condition, containing copper and manganese.

Gibson reported on rotating-beam and repeated impact fatigue tests of both cast and wrought aluminum alloys before the ASTM in 1920 (**8**). Since then there has been continuous investigation of the fatigue properties of the light alloys in this country. Early in this work, differences were noted between the behavior of some of the non-ferrous metals and that previously observed for some of the ferrous metals. The outstanding difference noted was the apparent absence of definite endurance limits for the non-ferrous light metals.

The invention by Wilm in 1911 of the high-strength, heat-treatable aluminum alloy, Duralumin, provided a suitable material for structural applications wherein a high ratio of strength to weight was of paramount importance. This material was of particular interest to aircraft designers and was first used extensively in the structural framework of lighter-than-air craft, but soon thereafter in heavier-than-air craft. Improved aluminum alloys of the Duralumin type were developed shortly after World War I and found uses not only in aircraft but in other fields. In these early applications of the heat-treatable, high-strength aluminum alloys, comparisons of their properties with those of mild steel were often made. While the static mechanical properties compared favorably with those of mild steel, the lower fatigue strengths of the newer metals were noted. The use of aluminum alloys in aircraft called for relatively high design stresses and repetition of stresses under service conditions. Consideration of these facts stimulated the early investigations of the fatigue properties of the heat-treatable aluminum alloys.

Appreciable improvements have been made in the static mechanical properties of aluminum alloys in recent years. These increases in the mechanical property values, particularly of the yield strength values, have led to the use of still higher design stresses in machines and structures. The fatigue strengths of these various alloys, however, have not been increased proportionately, as may be noted in Fig. 2. Occasionally, this situation has not been suitably considered by the designers of structures expected to withstand repeated loads, with the consequence that some fatigue troubles have occurred.

The appended bibliography of papers reporting on the fatigue properties of aluminum affords ample evidence of the attention given to the subject over the past thirty-odd years. These studies are continuing and are being expanded, with the result that today there is available an imposing amount of fatigue information on aluminum.

FACTORS AFFECTING FATIGUE STRENGTH

The fatigue strengths obtained from tests of the various products made from the many different aluminum alloys are affected by a rather imposing list of factors. While it is easy to obtain general agreement on the inclusion of the various items, the relative importance or significance of each is often merely a matter of opinion not substantiated by adequate data. The factors generally considered of major importance will be discussed in terms of their effects on the fatigue properties of aluminum alloys in their present commercial forms and conditions.

Testing:

The many factors that may affect fatigue data, from the testing viewpoint, are treated in considerable detail in the "Manual on Fatigue Testing," published by this Society in 1949 (**251**). Compliance with the recommended practices contained in this manual is virtually mandatory if satisfactory fatigue results are expected. The recommendations given probably should be considered as minimum requirements agreed upon by those experienced in making fatigue tests at the time the manual was written. Some materials may require even further attention to details. Undoubtedly, as the need for additional limitations is proved, the necessary requirements will be included in revisions of this manual. The nomenclature recommended in the manual is followed in this paper. The endurance limit values for aluminum alloys are based on their withstanding 5×10^8 cycles of stress without failure, generally using the rotating-beam test wherein the mean stress is zero.

The type of test—rotating-beam, axial- (or direct-) stress, or repeated-flexure—used in obtaining fatigue data affects the numerical values obtained for aluminum, as for other metals (**219**, **265**). The differences in values, however, are not always consistent. In general, the direct-stress test gives somewhat lower fatigue strengths than the rotating-beam test using solid specimens, but comparable data are obtained if thin-walled tubular specimens are used. The repeated-flexure type of test usually gives results in reasonable agreement with the rotating-beam type. The direct-stress and flexure types are often better suited than the rotating-beam type for stresses in the plastic range.

Some fatigue data have been reported for tests involving only compressive stresses (**346**). These and other unpublished results for some of the aluminum alloys are in qualitative agreement in showing that considerably higher ranges of stress are obtained in compression than in tension. Furthermore, the ranges of stress are higher when the stresses are entirely in compression than when the stress cycle involves tensile stresses. It is also worthy of note that when the stresses are within the compression range, in the case of the aluminum alloys, the specimens withstand the loads imposed on them for a very large number of cycles after the initial fatigue cracks are observed. This behavior, of course, is in rather marked contrast to that observed when the repeated stresses are in the tension range.

Most of the small amount of combined-stress fatigue testing of aluminum has been done in studies of theories of failure (**262**, **263**, **401**, **437**). When combined stresses are produced by internal pressure and axial load on specimens of extruded aluminum alloy tubes, the test results indicate an apparent anisotropy of the material. Since axial-load tests on specimens from other wrought products show no significant effects of grain direction, it seems reasonable to believe that the apparent anisotropy in tubes may be caused by other factors, such as surface finish on the inside of the tube. The investigators conclude that additional tests under other states of stress are needed.

Much emphasis has been put on the details of the finishing procedures used for fatigue specimens. The object, of course, is to obtain specimens with very smooth surfaces without changing the properties of the material. Various chemical treatments and etching procedures have been used for finishing fatigue specimens of aluminum. In some instances such procedures have given satisfactory results; but in others the reagent attacks grain boundary constituents or causes minute pits in the surface, either of which can affect the fatigue results adversely.

It is practically impossible to machine fatigue specimens (or tension test specimens (**412**)) from annealed high purity aluminum without affecting the test results appreciably. So far, the only satisfactory solution to this problem has been to machine specimens from rather severely cold-worked metal, then anneal the finished specimens. Fatigue data for fully annealed aluminum of very high purity probably are of questionable character because of the difficulties involved in preparing and testing the specimens.

Fatigue tests have been made at the Aluminum Research Laboratories of the Aluminum Company of America using specimens finished by a light buffing operation or by a careful polishing procedure ending with the use of fine crocus paper or, in the case of the harder alloys, finished by using only a careful machining operation. Although other sources (**293**) have reported results showing that appreciable differences in fatigue properties can be obtained depending on the finishing details, it would appear that, for aluminum alloys, any one of two or three different methods of finishing the specimens can be used satisfactorily if proper attention is given to the details of the method selected.

Speed of testing is one of the factors that is often given major consideration when making fatigue tests of metals. It undoubtedly merits such attention when the stresses used are in the plastic range of the material and considerable heating occurs. Much less trouble from this source is found when testing aluminum alloys than when testing ferrous and nickel-base alloys. Fatigue tests of a few of the high-strength aluminum alloys have been made at various speeds, ranging from 12 to 30,000 cpm, at room temperature, without any significant effects on the test values (**59**, **303**). The effects of speed at elevated temperatures, however, have not been so well defined. The problem presented is complex because of the increasing influence of creep as higher temperatures are used.

There are many other details involved in the testing technique which must receive more than the usual attention accorded them in static property tests in order to obtain good fatigue results. Some of the more important ones are alignment of specimen in the testing machine; vibration during testing; inertia effects of loading devices; protection of specimen from deleterious atmospheric conditions; uncontrolled temperature effects; proper fitting of specimens in machines, collets, or chucks; undue stressing of specimens by grip adjustment; critical vibrational speeds; improper and excessive stressing encountered during starting of testing machine. The quantitative significance of each of these items varies with the alloy, type of fatigue test, the specific testing machine, and type of specimen used. Suitable consideration of all these details should decrease the number of tests necessary to define the fatigue properties of a metal.

There has been a substantial increase in the number of investigators and agencies making fatigue tests of aluminum alloys during the past few years. Comparisons of results available from these many sources often reveal appreciable differences in data for the same material. Questions naturally arise as to the reason for these discrepancies; it is recognized that they might result from any one or a number of the many factors affecting the fatigue strength values. For instances where comparisons can be made using commercial products having the same nominal composition and static mechanical properties, and where the same nominal type of test specimens, machines, and technique were used, it would appear reasonable to give major consideration to two factors: (*a*) variation in the samples of the material and (*b*) variations in the testing technique used.

As an example of such a situation, the aluminum alloy 24S, which has been widely used throughout the world for many years in aircraft construction, has been selected. Extensive fatigue data for a number of different products of this alloy, and from many sources, are available. First, such data have been obtained over many years' time, for the various commodities, by a single laboratory. Secondly, such data are available from a number of different sources in this country, each of which is presumably following the fatigue testing practice recommended by this Society and using material made in this country. Finally, some fatigue data from sources outside of this country are available. These foreign data have been obtained from tests of similar material, but using, in most cases, somewhat different types of testing machines and procedures.

As an introduction to the comparisons about to be made, fatigue strength data of the type to be used are shown in Fig. 3. These data were obtained using the rotating-beam type of testing machine and specimen. Fatigue test results

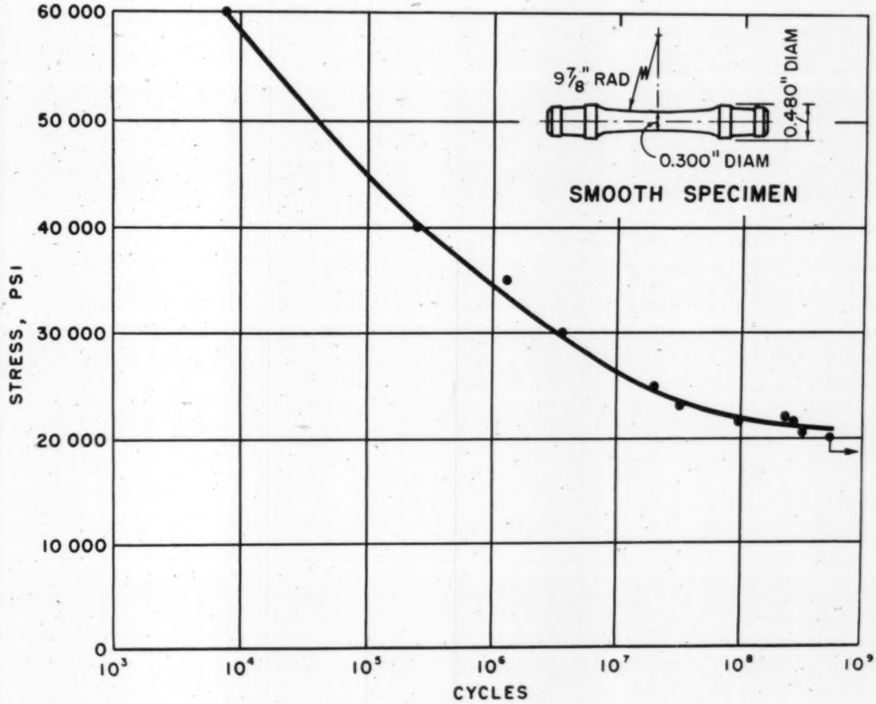


FIG. 3.—Fatigue Curve Showing Unusually Consistent Data.

exhibiting the consistency shown by this series are generally considered as not only giving the fatigue strengths for various numbers of cycles, but also as evidence of the good uniformity of the material and the high degree of accuracy of the data. When interpreting such data, however, conclusions reached should be restricted by stating that the particular sample used was uniform, the specimen preparation and testing conditions were controlled within close limits, and consistent results were obtained. Experience has demonstrated that fatigue results having the same satisfactory consistency, but differing appreciably in numerical values from the data shown in Fig. 3, can be obtained when the same material is tested by another agency using the same nominal testing procedure. When comparing such results, it is often difficult to decide or demonstrate which set of data is the more nearly correct.

Fatigue results such as shown in Fig. 4 are more often obtained, and the scatter is characterized as being typical of fatigue tests in general, typical of the material tested, typical of the specific type of fatigue test used, or perhaps even typical of similar data from the particular source offering the data. In general, the majority of fatigue test data in any given series of tests exhibits some scatter, and various methods have been suggested for interpreting such results toward the end of reaching answers as definitive as possible for fatigue strengths of materials. A common procedure is to present a faired curve through the plotted data points, drawn in by inspection or with the assistance of least squares, in an attempt to obtain an average curve. The statistical ap-

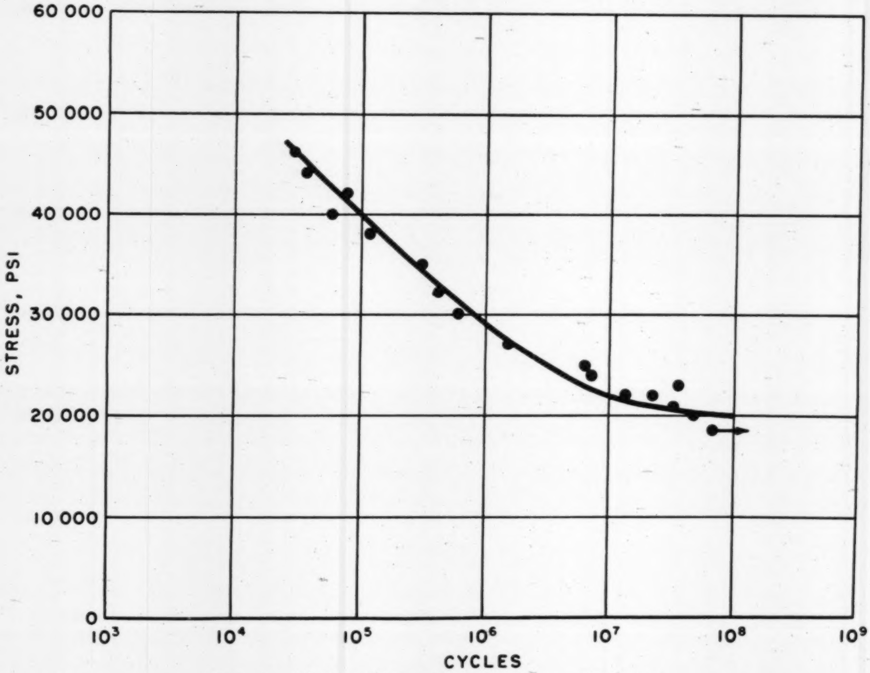


FIG. 4.—Fatigue Curve Showing Normal Scatter.

proach generally requires ten, twenty, or more tests at each stress level and may give a more precise answer for each lot of material tested. The number of specimens, when compounded by the number of lots required statistically to represent a given commodity produced over a reasonable period of time, makes the amount and cost of fatigue testing required prohibitive in most instances.

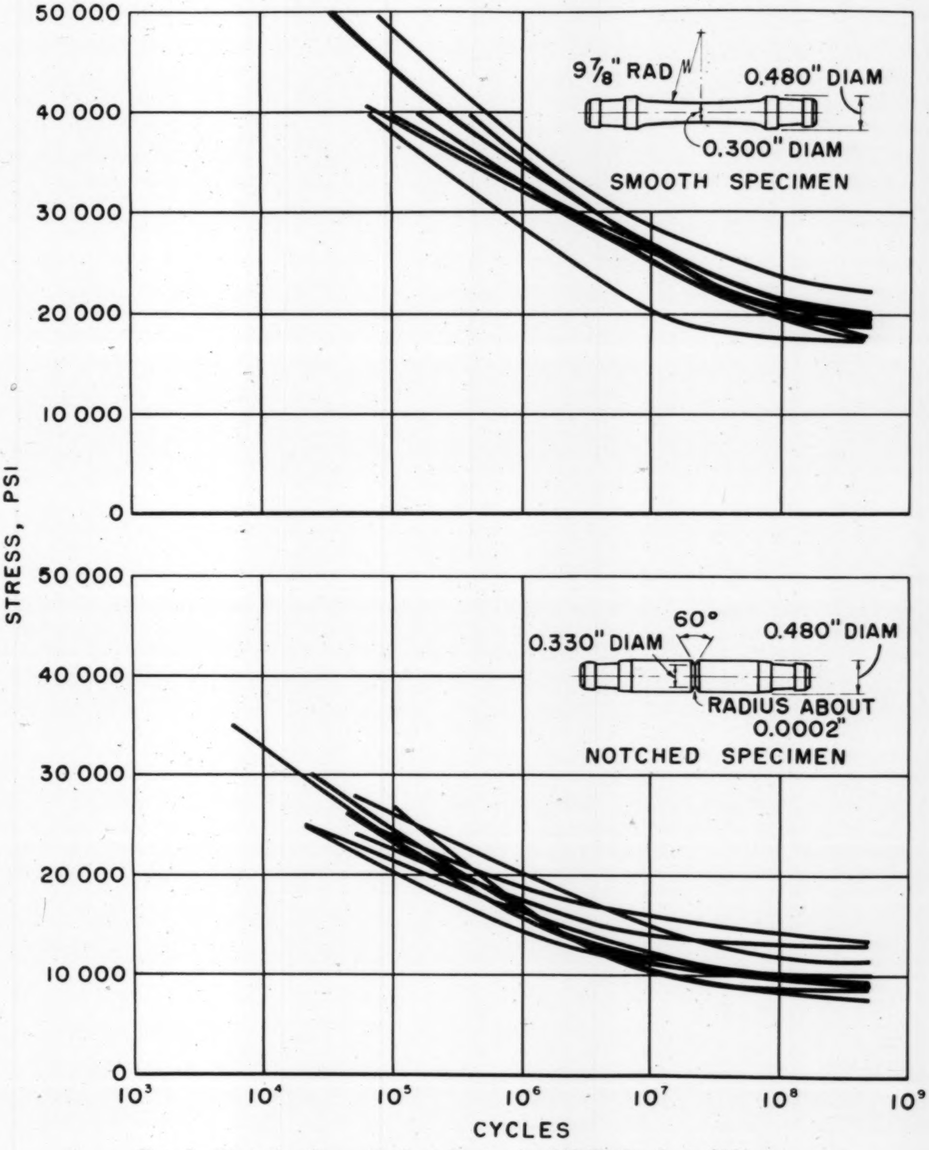


FIG. 5.—Rotating-Beam Fatigue Curves for 24S-T4 Products (Alcoa).

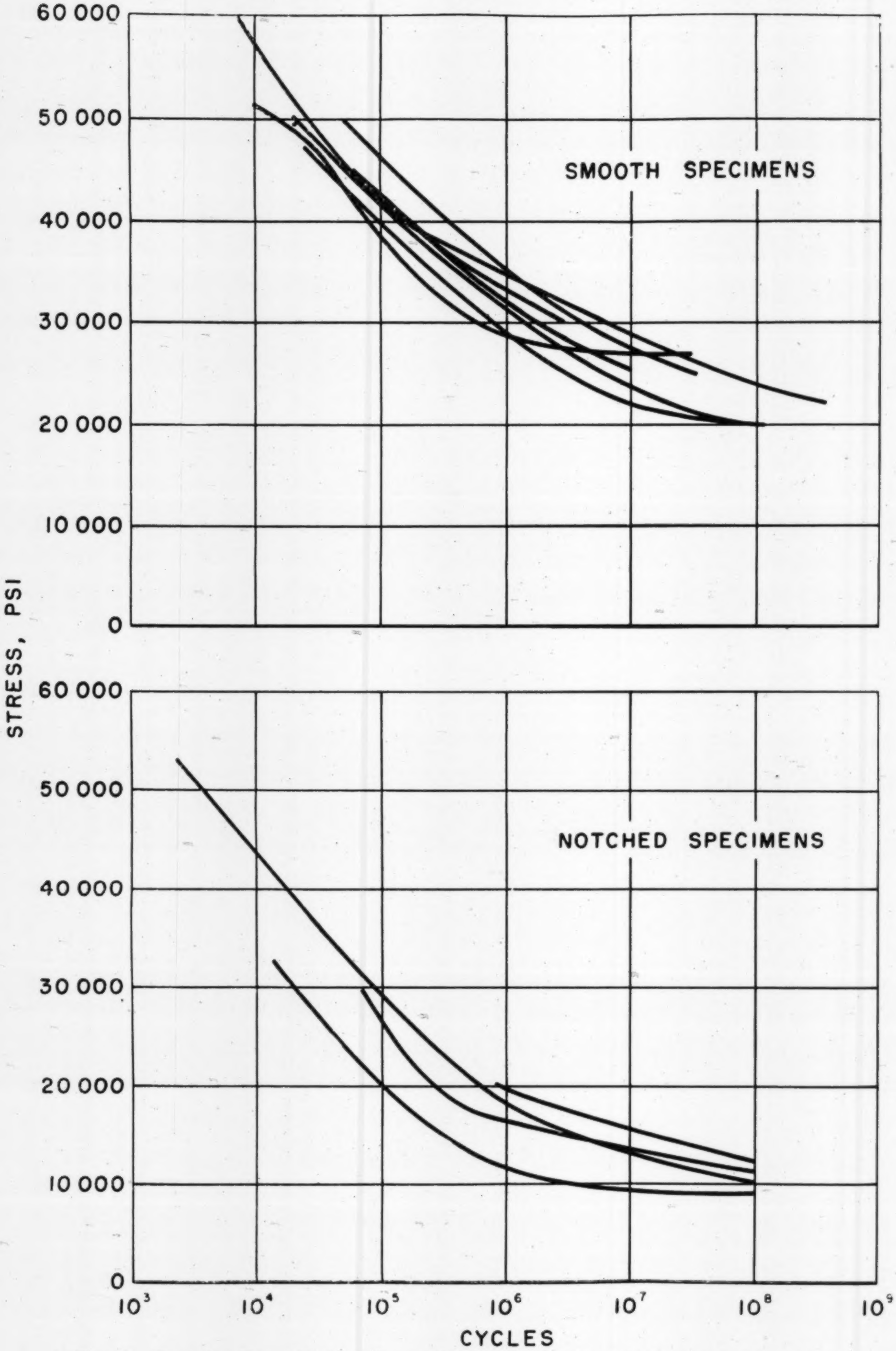


FIG. 6.—Rotating-Beam Fatigue Curves for 24S-T4 Products (Other U. S. Sources).

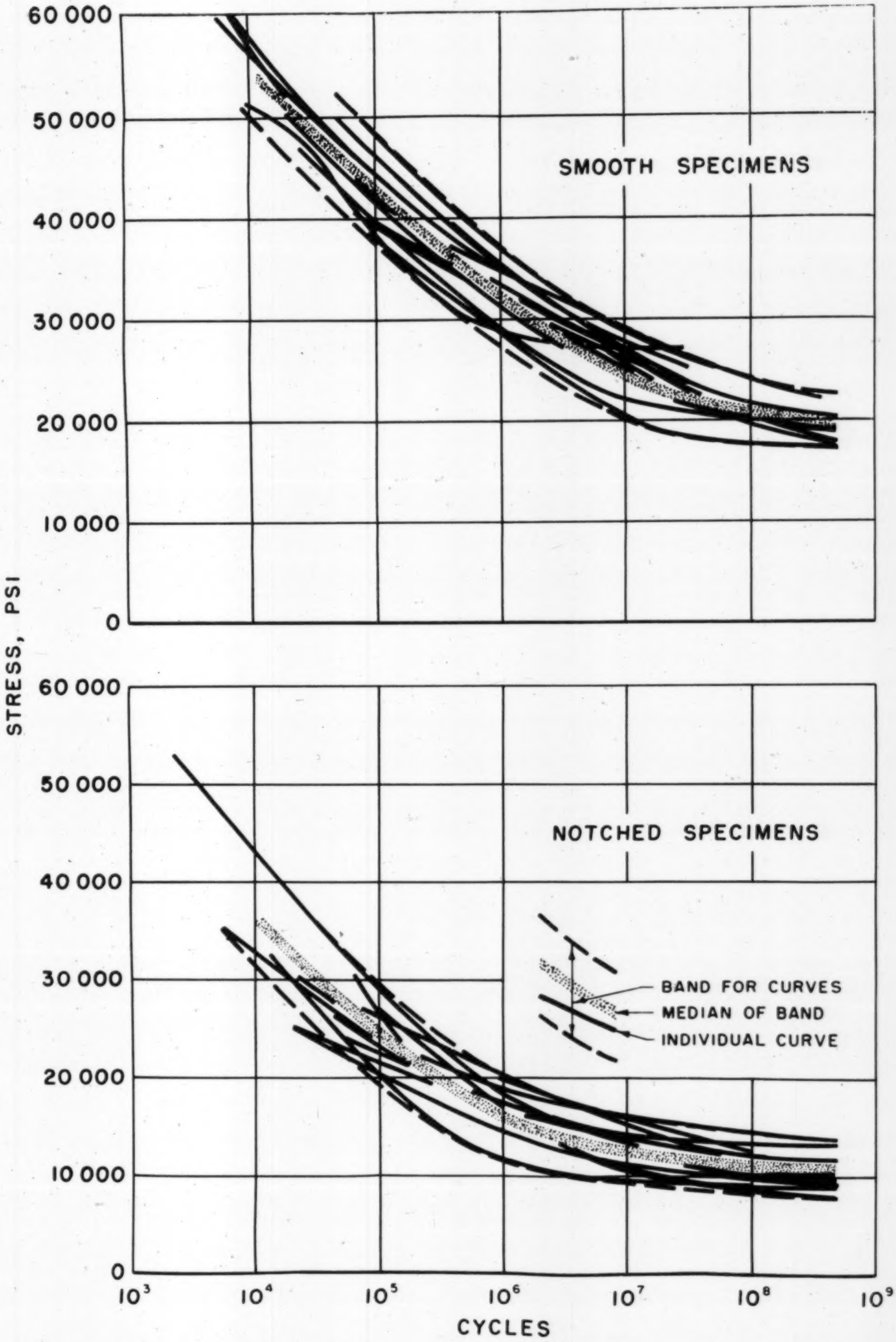


FIG. 7.—Rotating-Beam Fatigue Curves for 24S-T4 Products (Alcoa and Other U. S. Sources).

The situation is further aggravated if enough tests are included to cover adequately the testing variables involved.

For the comparisons in the example chosen for the immediate discussion, average or faired fatigue strength curves are used. These curves represent various samples of different wrought products made from the same aluminum alloy, having the same heat treatment, and tested by one laboratory with careful attention to the testing details. These are shown in Fig. 5 for smooth and notched specimens. A comparison is then made as shown in Fig. 6 with fatigue data from various other sources in this country (**219, 360, 384, 398, 435, 449, 473**). These results have been further combined in Fig. 7 and scatter bands or envelopes indicated that include all the domestic fatigue curves. With such fatigue data available, a mean or typical curve can also be established, and the band shown may be considered as defining approximately the expected variations under the existing conditions.

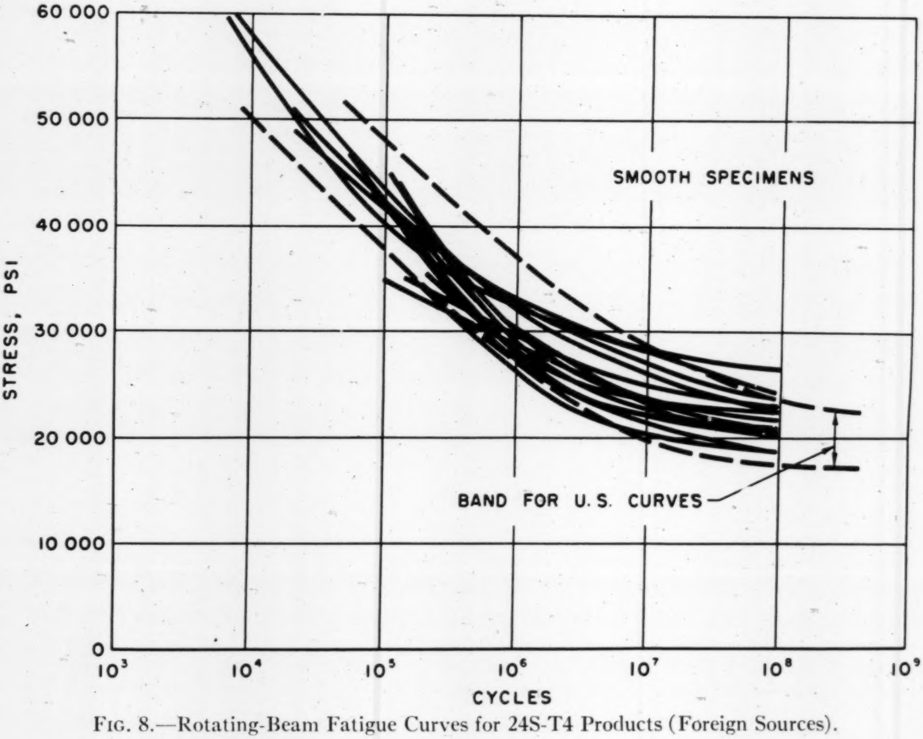


FIG. 8.—Rotating-Beam Fatigue Curves for 24S-T4 Products (Foreign Sources).

In the compilation of fatigue data, following the method just described, a tendency has been observed for the width of the scatter bands to increase as the amount of data increases. In Fig. 8 are shown similar smooth specimen fatigue data from foreign sources (**281, 293**) and the scatter band for the domestic data. It should be noted that some individual fatigue test values would be expected to fall outside of the band, depending on the scatter of results for the average curves defining the boundaries of the bands.

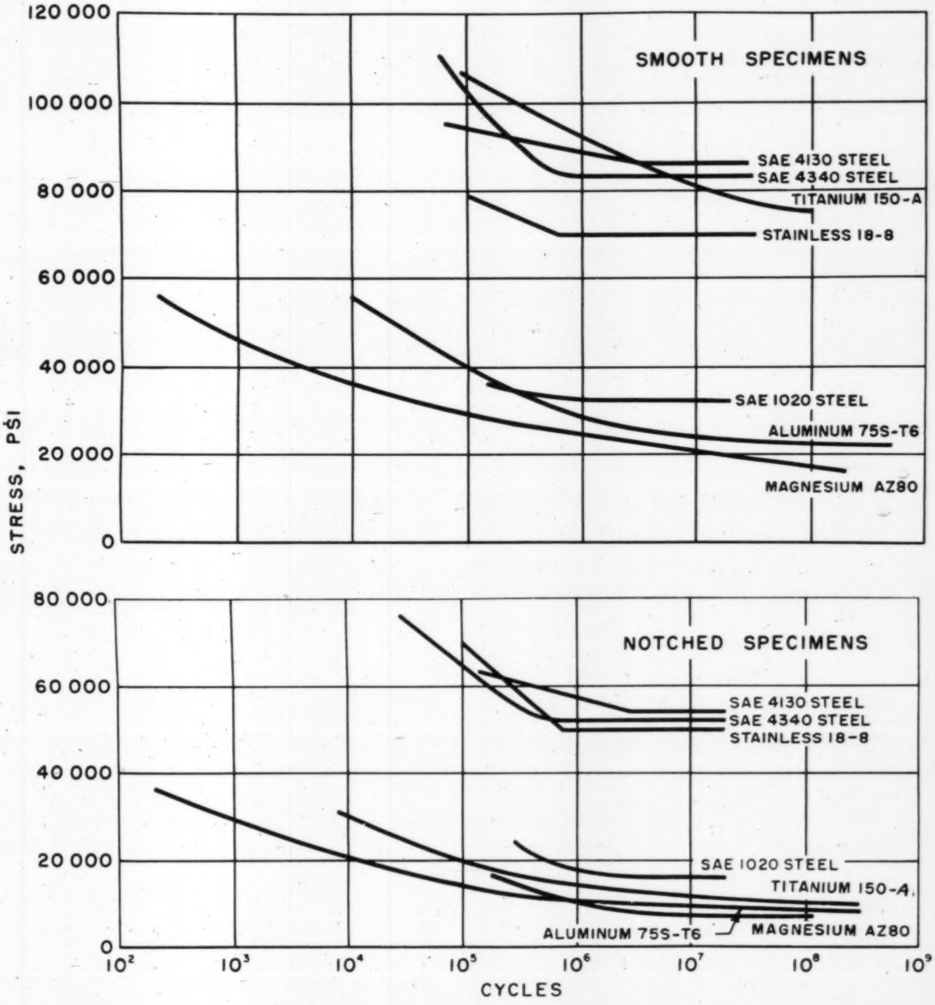


FIG. 9.—Rotating-Beam Fatigue Curves.

It would also appear reasonable to expect similar variations in fatigue data obtained from tests of other alloys. Unfortunately, such large amounts of data as those just discussed are not available for all the aluminum alloys.

The rotating-beam type of fatigue test, used in the comparisons just made, is probably the most widely used type. It is also a type of test in which close agreement is obtained, when using smooth specimens, between the actual stresses and the desired stresses. It would be expected, therefore, that data from this type of test from different sources would show closer agreement than fatigue data obtained using other types of fatigue tests involving specimens, machines, and testing techniques which are not so well standardized. The differences in results, evident throughout the comparisons, cannot be definitely ascribed to material or testing variations. It seems evident, however, that there is much room for improvement in the many details involved in making fatigue tests of this type if more definitive data are to be obtained.

TABLE I.—MECHANICAL PROPERTIES OF SOME METALS.

Metal	Tensile Strength, psi	Yield Strength (0.2 per cent offset), psi	Elongation in 2 in., per cent	Endurance Limit, psi		d/D[b]	Endurance Ratio	Fatigue Strength Reduction Factor
				Smooth Specimen	Notched Specimen[a]			
SAE 4130 steel	139 000	120 000	18	86 000	54 000 (2)	0.83	0.62	1.6
SAE 4340 steel	163 700	157 200	16	83 000	52 000 (2)	0.86	0.51	1.6
Titanium 150-A	150 000	135 000	16	76 000	10 000 (1)	....	0.51	7.6
Stainless 18-8	133 500	109 000	32	70 000	50 000 (2)	0.83	0.53	1.4
SAE 1020 steel	62 000	32 300	35	32 000	16 000 (3)	0.93	0.52	2.0
Aluminum 75S-T6	82 000	72 000	11	22 000	9 000 (4)	0.69	0.27	2.4
Magñesium AZ80	53 900	41 200	7	16 000	8 000 (2)	0.86	0.30	2.0

[a] Radius of notch: (1) 0.005 in., (2) 0.01 in., (3) 0.02 in., (4) 0.0002 in.
[b] Ratio of diameter at root of notch to major diameter.

Different Metals:

Data for a number of different metals of interest in the aircraft field, obtained from the most widely used type of fatigue test, are shown in Fig. 9 (**88,193, 241,347,382,383**). These data are from tests of only one sample of each material. It may be noted that the range of endurance strengths obtained from the smooth specimen tests is from about 16,000 to 86,000 psi, and for the notched specimens from 8000 to 54,000 psi. The fatigue strength reduction factors and endurance ratios have been indicated in Table I, but these should be considered as only approximate and probably not typical, because of the paucity of data.

The differences in fatigue strengths between the smooth and notched specimen results emphasize the marked effects of geometry on fatigue strength.

The fatigue strength values usually given for metals are those obtained from smooth specimens, but the designers of machines and structures expected to withstand repeated loads should be more interested in the notch specimen fatigue data. Unfortunately, there currently exists no standard notch fatigue specimen, and the numerical values obtained from such specimens depend upon the geometry of the notches used. This is illustrated by the data shown for two high-strength aluminum alloys in Fig. 10. It may be noted also from Fig. 9 that a sharp notch tends to minimize the effect of differences in the fatigue strengths of the different metals.

Different Aluminum Alloys:

There are available today many different aluminum alloys in both cast and wrought forms. These alloys exhibit wide ranges in static mechanical properties, as shown by the selected examples given in Fig. 2. Various tensile and yield strengths shown are the result of differ-

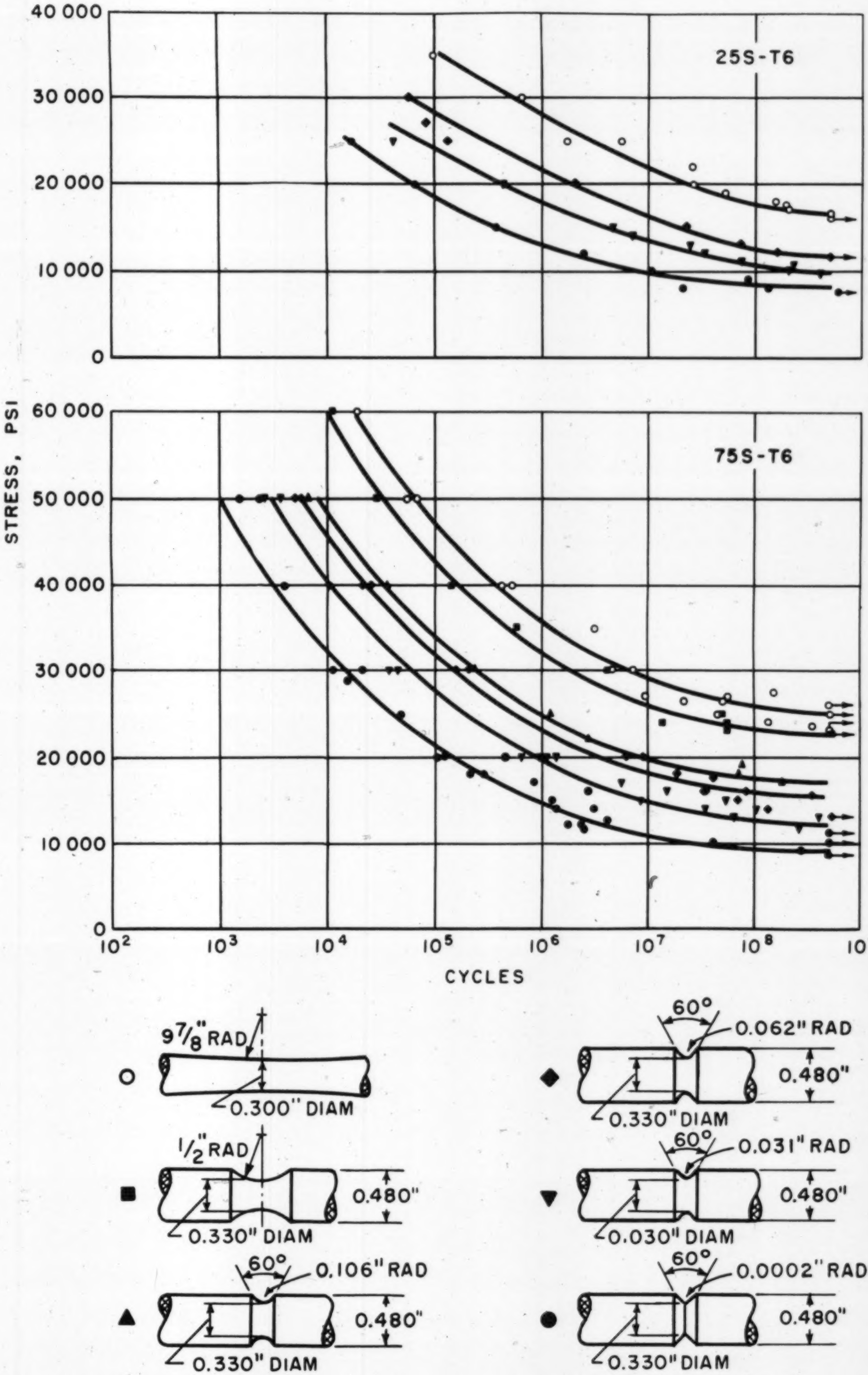


FIG. 10.—Effects of Radius of Notch on Rotating-Beam Fatigue Strength.

ences in chemical composition, cold working, heat treatment, or combinations of these factors.

From the fatigue results for aluminum alloys, obtained with smooth specimens and tested at room temperature, it is evident that rather wide variations in chemical composition can exist without causing appreciable differences in the fatigue strengths, particularly for 10^6 or more cycles of stress. For the low numbers of cycles, below about 10^4, differences are found which undoubtedly are influenced by the differences in static tensile properties of the various alloys. When severely notched specimens are used, the effects of composition and temper are even less pronounced and generally are of no practical significance.

Cast versus Wrought Alloys:

There are a greater number of aluminum alloys available for use in the form of castings than in the form of wrought products. Limitations involved in shaping metal into the various wrought product forms restrict or exclude the use of many of the alloys in the wrought forms. In general, there are four types of castings: those made in sand molds, those made in plaster molds, those made in metallic or permanent molds, and those made in metallic molds with molten metal introduced into the molds under relatively high pressures (die castings).

Extensive fatigue data for most of the commercial aluminum alloys, both as sand and permanent-mold castings, have been reported in the literature (**419,487**). Data from both smooth and notched specimens, tested in the rotating-beam type of fatigue machine, are presented. The results from this extensive work indicate clearly the absence of any very significant differences in the fatigue strengths for lives of about 10^6 or more cycles, throughout the entire group of alloys tested. The data from the smooth specimen tests show extensive overlapping of the results for the permanent-mold-cast alloys and those for the sand-cast alloys, with slight superiority shown by the average fatigue strengths of the permanent-mold-cast alloys over the average fatigue strengths of the sand-cast alloys. When using the notch type specimens, however, no significant differences in fatigue strengths were observed between the permanent-mold and sand-cast alloys, as shown in Fig. 2. Aluminum alloys cast in plaster molds show no significant differences in fatigue properties from those of the same alloys cast in sand molds.

The die-cast aluminum alloys exhibit smooth specimen fatigue strengths quite superior to those found for sand and permanent-mold castings (**494**). Rather surprisingly, the fatigue strengths of the aluminum die castings are equal to those obtained for the highest static strength wrought aluminum alloy products for 10^7 or more cycles. This has been found to be the case for both the smooth and notched specimen data, and it is a fact which deserves serious consideration by designers of machines and structures where fatigue strength is important and where die castings offer other advantages.

The fatigue data for sand-cast aluminum alloys show rather small differences between the strengths of the smooth and the notched specimens. The average endurance limit for the entire group of notch fatigue tests of aluminum sand castings (7500 psi) is only about 1500 psi less than the average endurance limit for the smooth specimen data (9000 psi).

Greater differences may be observed between the endurance limits for the

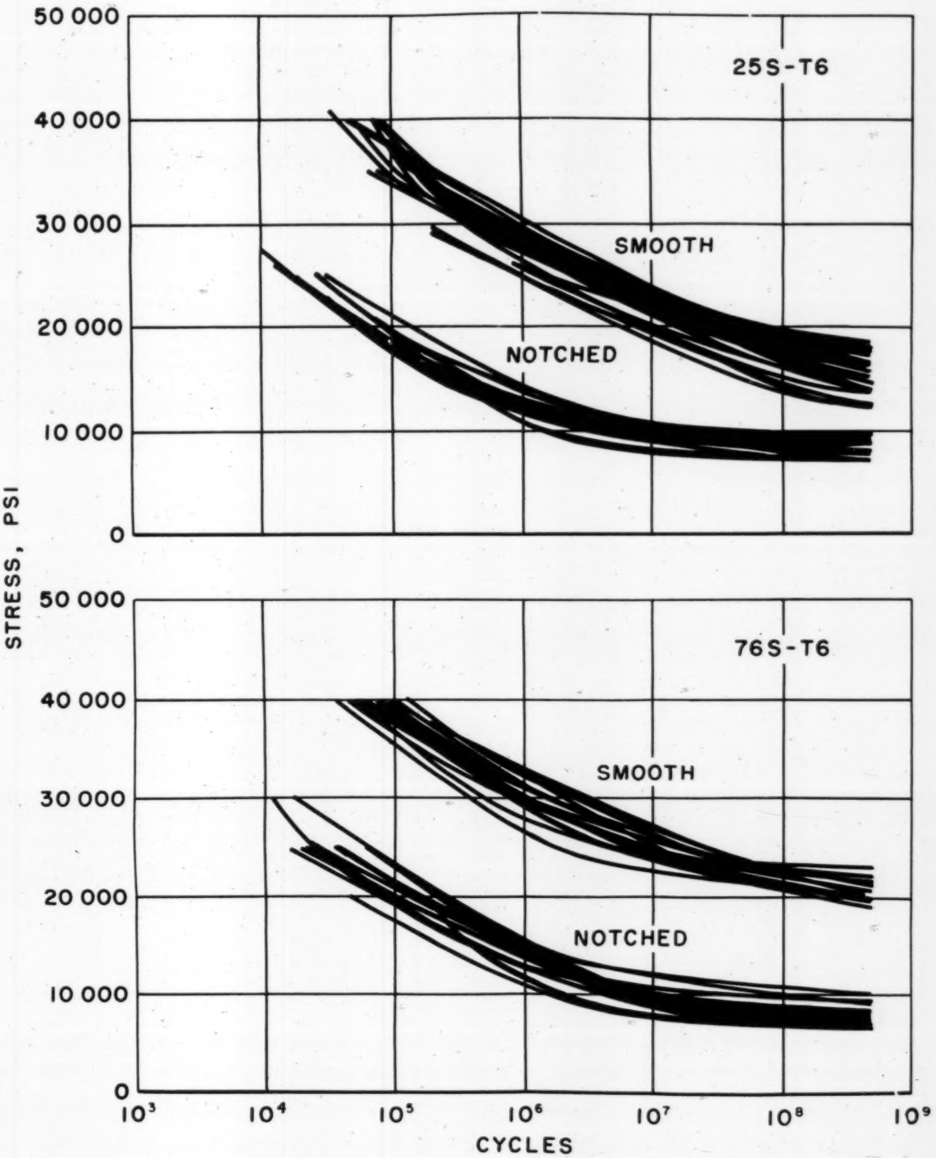


FIG. 11.—Rotating-Beam Fatigue Curves for Specimens from Aluminum Alloy Propeller Blades.

smooth (about 12,000 psi) and notched (about 7500 psi) specimens of the permanent-mold-cast alloys, with an average difference of about 4500 psi.

In general, the fatigue strengths of the wrought aluminum alloy products, using smooth specimens and the rotating-beam type of test, are appreciably higher than the fatigue strengths of the commercial sand-cast or permanent-mold-cast alloys. On the other hand, the fatigue data when very sharp notch type specimens are used show no significant differences.

The superiority in fatigue strengths of the wrought aluminum alloy products over the sand- and permanent-mold-cast alloys is what would be expected. The absence of any difference between the notch fatigue values might not be expected. This lack of difference would appear to emphasize the importance of the effects of geometry rather than those of composition, heat treatment, working, or ductility as usually determined, on the fatigue strengths of the aluminum alloys.

Wrought metal products usually originate from cast ingots. Depending upon the quality of such ingots, the various metal-working processes involved in producing wrought products may have beneficial effects on the fatigue properties of the final products. Most of the undesirable conditions obtaining in the ingots can be modified or corrected, so that the ultimate fabricated product will have improved fatigue properties. It has been demonstrated in the laboratory, however, that small, very high quality chilled cast aluminum ingots of both 75S and 355 aluminum alloys can be made in such a way that samples from them, given the usual heat treatments, will have smooth specimen fatigue strengths in close agreement with those obtained from 75S-T6 wrought products and the die-cast alloys. The notched specimen fatigue data from these special laboratory ingots, however, show no improvement over similar results from present commercial wrought products, sand castings, or permanent-mold castings. From these results, it is tentatively concluded that any improvement in the fatigue properties of wrought aluminum alloys by working is definitely dependent on an improvement in the quality of the ingots used in making a given product. Furthermore, if large commercial ingots or castings are made equal in quality to the special laboratory ingots just mentioned, no significant improvement in notch specimen fatigue values would be expected.

The relative constancy of the fatigue properties of an aluminum alloy product is shown by the data in Fig. 11. These tests results were obtained from aluminum alloy airplane propellers over a period of 17 years for the 25S alloy and 12 years for 76S alloy. Random sample blades were taken from the production lots at 6- to 12-month intervals. Fatigue specimens, both smooth and notched, were cut from the thin parts and the hubs of the blades and tested. During the period covered, numerous changes in fabrication procedure were made in order to improve the working of the metal, refine grain size, and obtain better dimensional tolerances and more uniform tensile properties. All the fatigue results obtained are shown. Detailed analysis of the data has revealed that during the past quarter century there have been no definite or significant differences among all the sample blades, nor between the more severely worked parts and the hubs.

Cold Working and Heat Treatment:

Cold working aluminum and its alloys increases their tensile and yield strengths with a sacrifice in ductility. Cold working also increases their smooth specimen fatigue strengths, but at a much lower rate and not in direct proportion to the increases in tensile or yield strengths. In general, the notch fatigue strengths are not appreciably affected by cold working. The endurance limits of some of the aluminum alloys in the fully annealed condition are equal to or greater than their yield strengths. This fact makes determination of the fatigue values difficult, if not impracticable, since stresses applied at or above the endurance limit plastically deform and cold work the metal with the result that the metal is no longer in the annealed condition. The fatigue strength of these annealed materials, as determined by current testing procedures, should be considered as actually applying to some intermediate cold-worked temper of the metal.

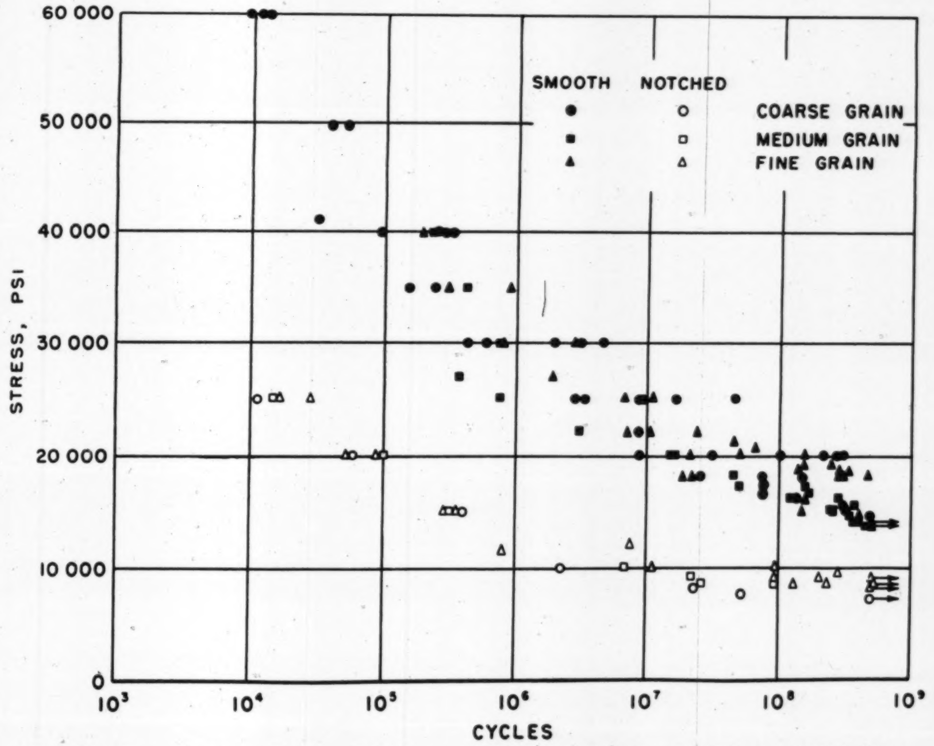


FIG. 12.—Rotating-Beam Fatigue Data for an Aluminum Alloy Showing Effects of Grain Size.

Almost all the heat-treatable wrought aluminum alloys, when heat treated from either the annealed or cold-worked condition, exhibit an increase in both the smooth and notch specimen rotating-beam fatigue strengths of about 50 per cent over those of the annealed material. The amount of this increase is approximately the same for solution treatment only as for solution treatment followed by artificial aging.

The heat-treatable aluminum alloys that can be further hardened by a precipitation heat treatment have appreciably higher tensile and yield strengths after precipitation hardening than after solution heat treatment only. The fatigue strengths after precipitation heat treatment, however, are no higher, and in some instances are slightly lower, than after solution treatment only. It may be noted, therefore, that the endurance limits for these alloys could not remain a constant function of their tensile strengths.

Superimposing cold work after heat treatment of the high-strength wrought alloys causes little, if any, increase in their smooth specimen fatigue strengths and no significant changes in their notched specimen fatigue strengths.

Grain Size and Direction:

Differences in fatigue properties of metals are often attributed to grain size, where appreciable differences in grain size obtain. Fine grain size is frequently considered as enhancing fatigue strength. Numerous studies of aluminum alloys have been made for the purpose of correlating fatigue properties and grain size. The results have not been consistent in all instances, particularly when fatigue data from only two samples, apparently differing in grain size only, were compared.

Considerable fatigue data are now available for a number of different aluminum alloys which indicate that grain size probably has no significant effect on the fatigue strength. Some of these results for one alloy are shown in Fig. 12. Grain sizes ranging from very fine (170,000 per cu mm) to very large ones (0.003 per cu mm) have been used and found to give almost identical fatigue values.

The conclusion has tentatively been drawn that something other than grain size was probably the cause of differences in fatigue strengths found and attributed to grain size simply because a difference in grain size was observed.

Grain direction *per se*, in wrought aluminum products, has no significant effect on the fatigue properties (**308**). In some specific instances, conditions of lined-up constituent or highly elongated and unhealed porosity have been found to affect both the fatigue strength and the tensile properties of the material. In the absence of such conditions, but with pronounced grain flow, the fatigue properties are practically the same in all directions.

Inclusions and Voids:

The particles of intermetallic compounds occurring in aluminum alloys are essential in obtaining the high tensile properties of the heat-treatable alloys. These particles, sometimes erroneously classified as inclusions, appear to have no deleterious effects on the fatigue properties of the material even though much enlarged by agglomeration. X-ray examinations of broken fatigue specimens show clearly that the fatigue cracks nearly always avoid the large particles, and the fatigue strengths obtained agree very closely with those of similar samples in which the particles are very small and uniformly dispersed. An example of such particles is the chromium constituent sometimes occurring in 75S products (**454**). Nonmetallic inclusions or particles of metals that will not alloy with aluminum can affect the fatigue strength adversely, depending on their size, shape, and location in the specimen.

Internal seams, voids, intergranular corrosion, and unhealed porosity will have deleterious effects on the fatigue properties of aluminum, particularly when smooth laboratory-type specimens are used. Generally, however, such undesirable conditions are not as effective in lowering the fatigue values as the stress concentrations resulting from holes, abrupt changes in section, screw threads, keyways, tool marks, etc. Considerable fatigue data are available to substantiate this statement.

Porosity in aluminum castings affects the smooth specimen fatigue results, but over a wide range of size of voids, beyond that occurring in good commercial practice, it has no definite effect on the notched specimen fatigue strengths. Repair of blow holes and misruns in aluminum castings by welding and flush-dressing of the welds fully restores the fatigue properties if the welds are sound and well fused (**236**).

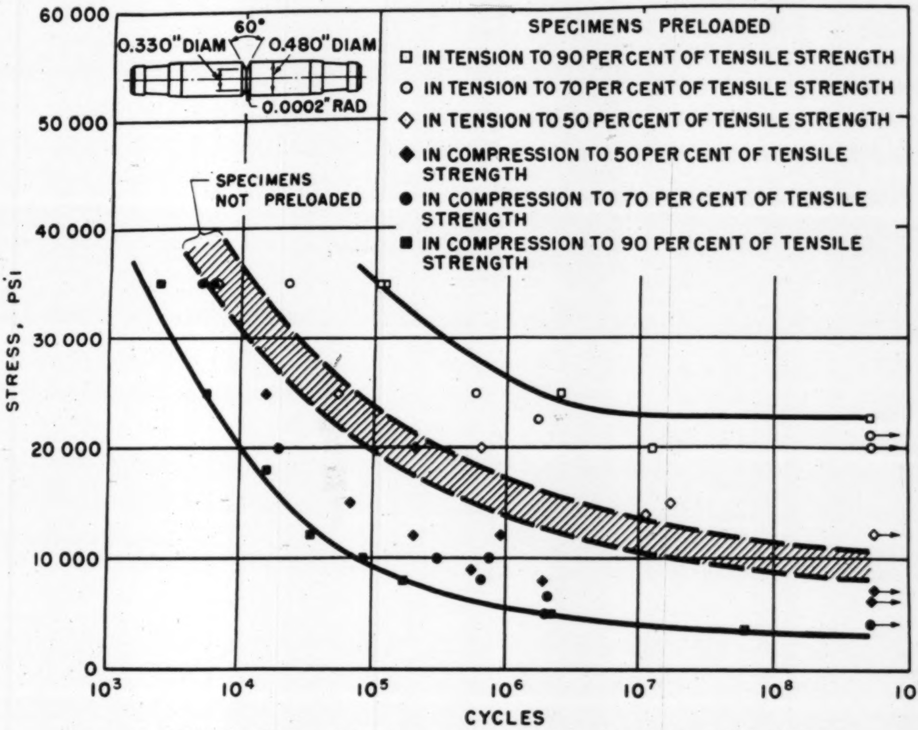


FIG. 13.—Effects of Internal Strain on Rotating-Beam Fatigue Strength of 75S-T6.

Internal Strain:

The magnitude and distribution of internal strains are generally recognized as affecting the fatigue strengths of metals (**153,357**). The effects can be of more or less significance, beneficial or deleterious, depending on the character, amount, and location of the strains. Procedures for inducing compressive strains by shot-peening, surface rolling, and heat treatment are widely and successfully used to decrease the tensile stresses in parts subjected to repeated loads. These procedures affect aluminum as other metals but may require minor modifications of the details involved when applied to the different alloys, tempers, and conditions (cast or wrought). Each application appears to require specific consideration for optimum results.

Laboratory demonstration of what can be accomplished by internal strain in changing the fatigue strengths of severely notched specimens of 75S-T6

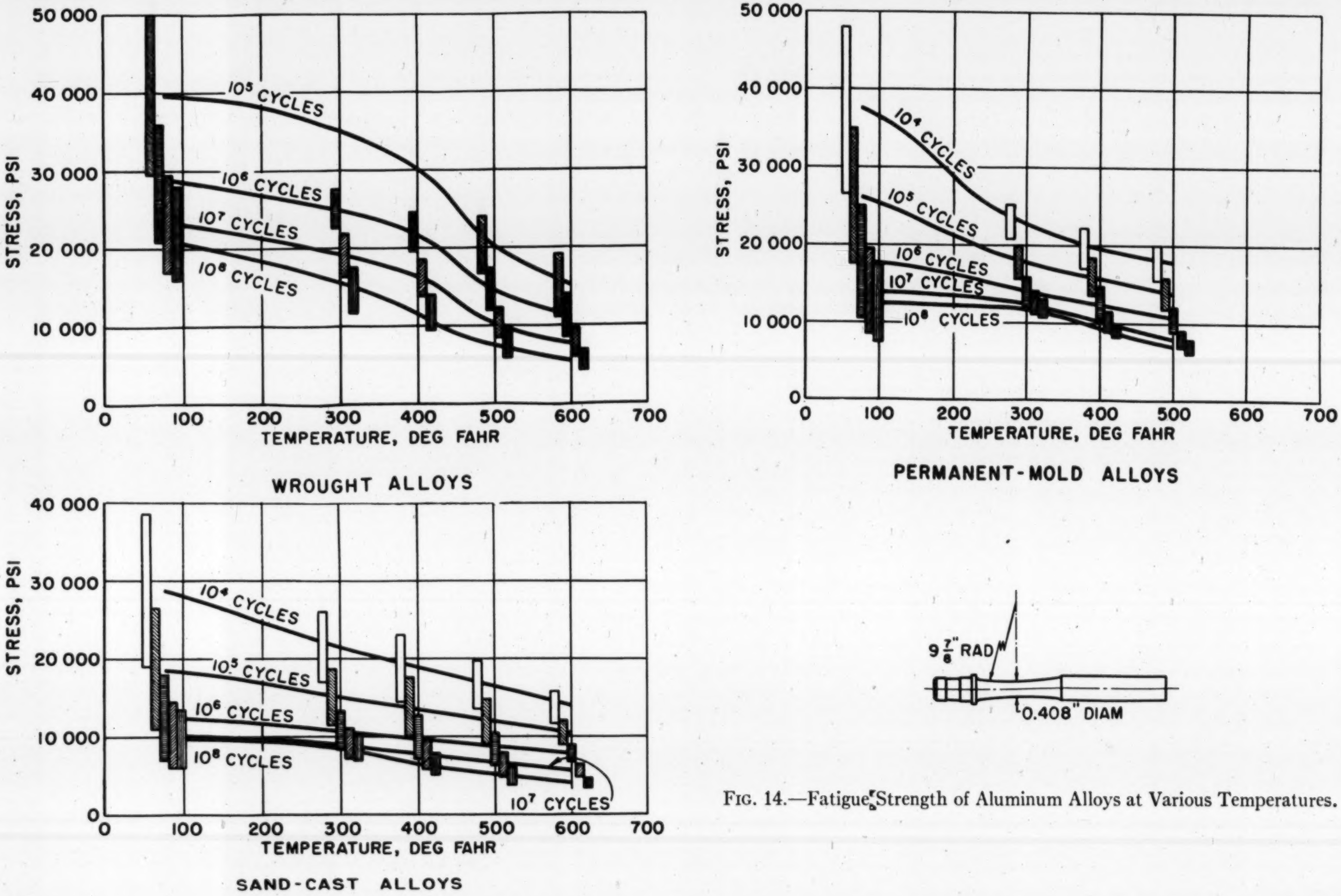


FIG. 14.—Fatigue Strength of Aluminum Alloys at Various Temperatures.

is shown in Fig. 13. Some of the specimens were preloaded in tension to 50, 70, or 90 per cent of their notch tensile strengths, thus leaving various unknown amounts of residual compressive strains at the root of the notch upon release of load. Other specimens were likewise loaded in compression initially, leaving similar residual tensile strains at the root of the notch. The ends of the specimens were then machined to fit the rotating-beam fatigue machines and tested in the usual manner. The shaded scatter band shown in Fig. 13 was obtained from notched specimens which had not been preloaded.

From these results, it can be observed that the highest preloading in tension (residual compressive strains) increased the notch endurance limit about 100 per cent, and similar preloading in compression lowered the notch endurance limit about 50 per cent compared to the original values. Preloading up to about 50 per cent of the notched specimen tensile strength had little if any effect, and 70 per cent preloading gave intermediate results.

These results may be helpful in planning or interpreting fatigue tests of preloaded structural parts which contain stress raisers. The data seem to suggest that maximum benefits require rather severe preloading, probably beyond that which could be used practically in many structures. In some cases, however, preloadings that could be used probably would offer worth-while benefits. Another rather important conclusion may be drawn from these data: internal strains of appreciable magnitude can exist in the material without affecting the notch fatigue properties.

Temperature:

The aluminum alloys show appreciable changes in their fatigue properties with temperature. In general, the fatigue properties increase as the temperature decreases below room temperature. For the higher temperatures, the fatigue strengths decrease in amounts depending upon the number of cycles, stress and temperature. For the larger numbers of cycles, beyond 10^6, the decreases in fatigue strengths of the sand- and permanent-mold-casting alloys appear to be negligible up to temperatures of about 300 F. Above this temperature the decreases are greater. The wrought alloys show somewhat larger decreases for temperatures above room temperature.

The fatigue strengths of all the commercial aluminum alloys tend to approach common values for temperatures of about 600 F. Results from a number of selected typical aluminum alloys in the wrought, sand-, and permanent-mold-cast conditions are shown in Fig. 14. These data were obtained from the rotating cantilever-beam type of fatigue test, using specimens of the dimensions shown in the figure and stressed at the rate of 3500 cpm.

The very few notch specimen fatigue data available for the aluminum alloys at elevated temperatures indicate that the fatigue strength reduction factors decrease as the temperature increases. As in the case of notch fatigue data at room temperature, the numerical values are affected by the geometry of the specimens used, but probably to a lesser extent at the higher temperatures.

Apparently no shear fatigue or combined stress fatigue data are currently available for aluminum alloys at elevated temperatures.

It is evident that much more fatigue data for the aluminum alloys at elevated temperatures are needed.

Size Effect:

It is necessary, when discussing size effect in relation to fatigue test results, to first define what is meant by "size effect." Most investigators of the fatigue properties of materials, when considering size effect, have in mind differences in fatigue strengths obtained using specimens geometrically similar but varying in cross-sectional dimensions. In contrast to this concept, it appears that there is a substantial group of engineering designers who prefer to include in the size-effect category a considerable list of factors resulting from the many details involved in producing the material, and in the designing and building of the machine or structure. The first concept should be understood as that applying to the discussion that follows.

Some fatigue data for a few aluminum alloys are available, obtained from the rotating-beam type of test, for specimens varying in diameter from about $\frac{1}{8}$ in. to 4 in. These data are not entirely consistent, but they indicate that there is no significant size effect throughout the range investigated. Certainly more data, extending over a greater size range and involving more aluminum alloys in various conditions, are needed before further conclusions can be drawn regarding size effect. Additional work should include both smooth and notch type specimens.

Coatings and Platings:

Products made from aluminum alloys invariably have on their surface a natural oxide film or coating. These coatings can be produced intentionally in various thicknesses and with differences in their density and structure The effects of these coatings on the fatigue properties of aluminum vary with the different kinds of coatings. In general, the thicker and harder coatings have the more pronounced effects on the fatigue strengths and, in some instances, cause significant decreases in the fatigue values (306). Where fatigue strength is important, the thick sulfuric acid type of anodic coatings should be avoided and the thin coatings of the chromic acid type used.

Many of the wrought high-strength

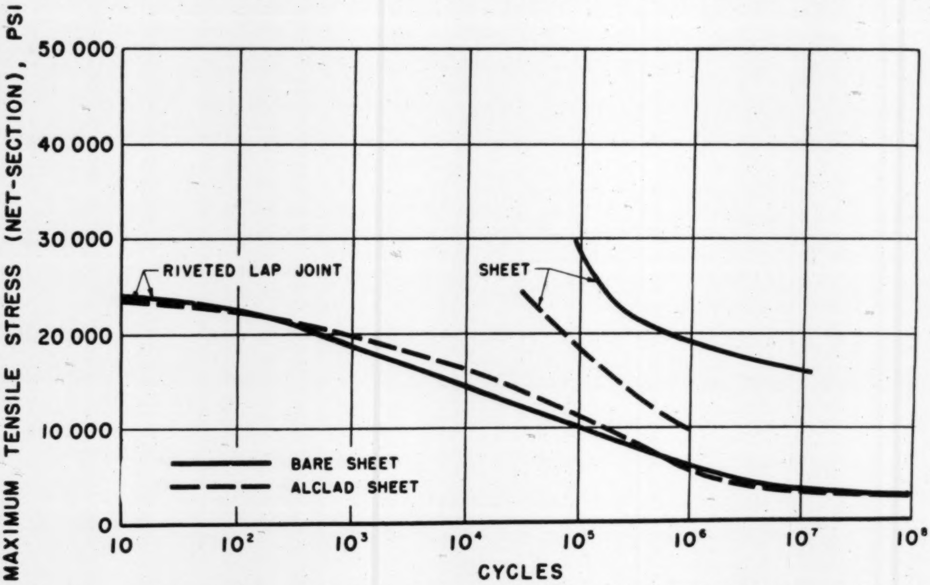


FIG. 15.—Axial-Stress ($R = -1$) Fatigue Curves for Bare and Alclad 75S-T6 Sheet and Joints.

aluminum alloys are produced in alclad form having a core of high-strength alloy to which are integrally bonded thin layers of pure aluminum or alloys of lower strength than the core. Such alclad products are essential for maximum protection against corrosion, but alclad sheet, for example, is found to have somewhat lower fatigue strengths, as shown in Fig. 15. The magnitude of the effects of these coatings on the fatigue strengths of the material in most practical applications is much less than the effects of geometric configurations resulting from design or fabrication details, as may also be seen from the results given in Fig. 15.

Metallic platings on the aluminum alloys may cause some decrease in the fatigue properties, depending on the kind and character of the plating. Some data are available for nickel and chromium platings (**456**). When the platings fail first, the fatigue cracks in the coatings act as stress raisers in the aluminum, resulting in decreased fatigue strengths. More fatigue data are needed for metallic coatings on aluminum.

Environmental Protection:

Most of the aluminum alloys have good or excellent resistance to corrosion, but none is immune to corrosion attack in all environments. Irrespective of whether the corrosive action is evidenced by pitting or by intergranular attack, the fatigue properties are adversely affected (**23,24,25,28,29,33,35**). Protection against most of the objectionable environmental conditions is adequately provided by selection of alloy, use of alclad products, anodic coatings, or painting.

Protection of aluminum against mechanical damage during fabrication into machines and structures, as well as under service use, is sometimes neglected or difficult to attain. The deleterious effects of tool marks, nicks, deep scratches, gouges, frettage, and severely deformed parts resulting from misuse or abuse have long been recognized and extensively discussed in the technical literature. These undesirable factors affect aluminum as they do other metals; therefore, they should be avoided, or at least minimized, where fatigue strength is important. The specific items just mentioned are but a few of the many that should be considered in effecting proper maintenance of structures designed and made to withstand repeated loads for long periods of time.

TABLE II.—FATIGUE STRENGTH REDUCTION FACTORS FOR COMMERCIAL WROUGHT AND CAST ALUMINUM ALLOYS.

	Range of Fatigue Strength Reduction Factors[a]
Wrought alloys in annealed condition	2 to 2½
Nonheat-treatable wrought alloys in -H series of tempers	2 to 3
Heat-treated wrought alloys	1½ to 2½
Sand-cast alloys	1 to 1½
Permanent-mold-cast alloys	1 to 2
Die-cast alloys	2½ to 3

[a] Values determined from rotating-beam tests of notched specimens of the type shown in Fig. 5.

The values given are average values for cycles ranging between 10^6 and 5×10^8.

Stress Raisers:

The many geometric configurations that function as stress raisers in metallic constructions are generally recognized but often neglected or ignored in design. These are the primary causes of the majority of fatigue failures. They may exist because designers often proportion parts to withstand only static loads or forces; because they strive to effect low cost of manufacture; or because of their unwillingness or inability to analyze the actual rather than the nominal or average stresses occurring in the critical parts of the structure under prescribed service conditions. Other stress raisers may originate during the fabrication of structures as well as during service.

It is desirable, wherever possible, to minimize or eliminate stress raisers in order to obtain optimum fatigue strength. Unfortunately, this cannot be done effectively in many cases because of the conventional methods used in joining the component parts of structures. In such instances, stress concentration or fatigue strength reduction factors for the materials considered may be helpful to the designers. Fatigue strength reduction factors for some of the aluminum alloys are given in Table II. These are the ratios of the fatigue strengths of the smooth and notched rotating-beam specimens previously described. The reduction factor is nearly constant for each of the groups of wrought alloy products from 10^6 to 5×10^8 cycles, but varies appreciably for lower numbers of cycles, depending on the specific material. The fatigue strength reduction factors for the die-cast alloy products are about the same as those for the wrought products, but the factors for the permanent-mold and sand-cast alloys are significantly lower.

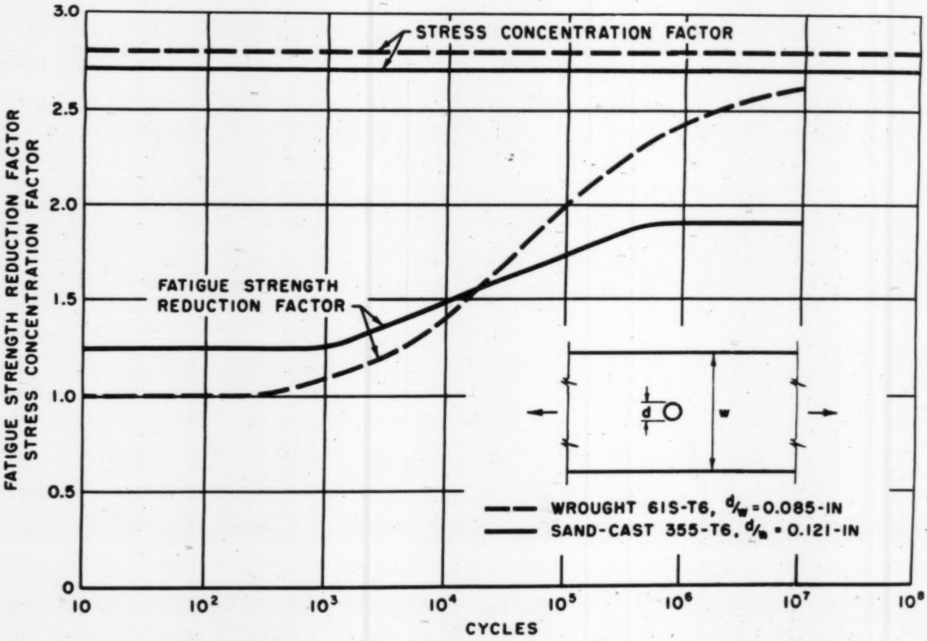


FIG. 16.—Fatigue Strength Reduction Factor ($R = 0$) for Wrought and Cast Aluminum Alloys.

Rather poor agreement is obtained between theoretical stress concentration factors and experimental fatigue strength reduction factors. Examples are shown in Fig. 16.

FATIGUE TESTS OF MACHINE AND STRUCTURAL COMPONENTS AND ASSEMBLIES

Results from fatigue tests of the types previously discussed are useful in the development of new alloys and metal-producing operations or modifications of these items, but generally are not suitable for direct use by the designer of structures. Since the "Achilles' heel" of a structure subjected to repeated loads is some stress raiser, there is real need for fatigue information concerning the various types of stress raisers found in actual structures. Data from service performance give the best answers to fatigue problems, and accelerated simulated service tests of complete structures are probably the next best source of answers. Much useful information, however, can be obtained from accelerated tests of the critical components of structures under controlled conditions that have some reasonable relationship to those anticipated in service. Correlation, wherever possible, of the data from these tests with service experience is desirable, but such tests can be used directly to compare different designs and thereby effect improvement in their fatigue strengths.

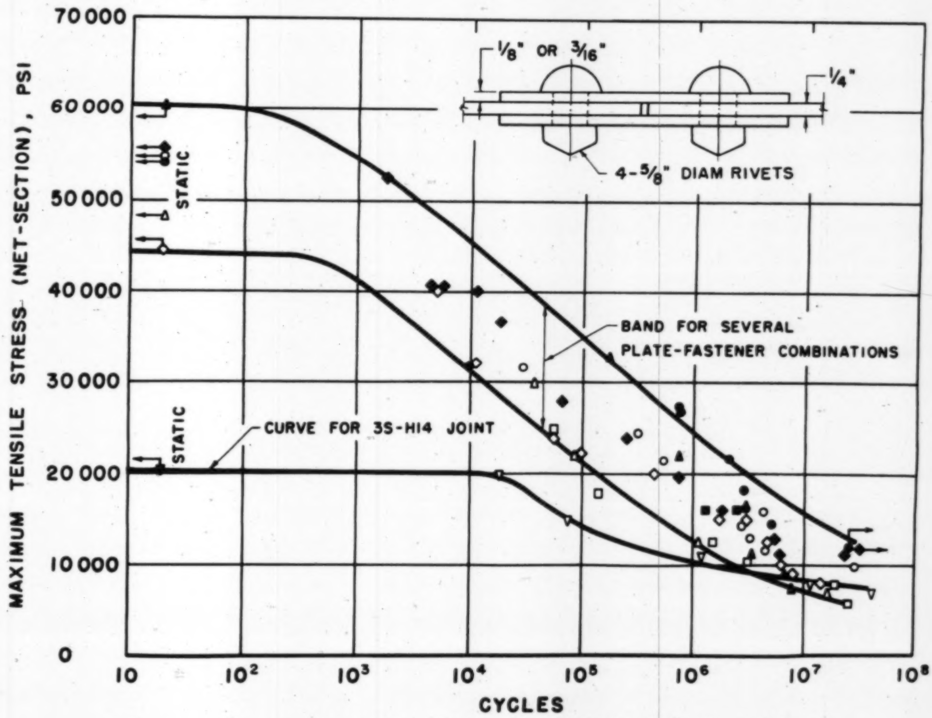


FIG. 17.—Fatigue Strengths ($R = 0$) of Riveted Double-Strap Butt Joints.

There are available extensive fatigue data from tests of aluminum structural components (**173,180,195,222,287,325,336, 486**) but not enough to answer all the recognized fatigue problems. Some of the more significant results from this investigational work will be discussed briefly.

The presence of unavoidable but severe stress raisers in fatigue tests of structures or their components appears to minimize or overshadow, at lives exceeding about 10^6 cycles, the effects

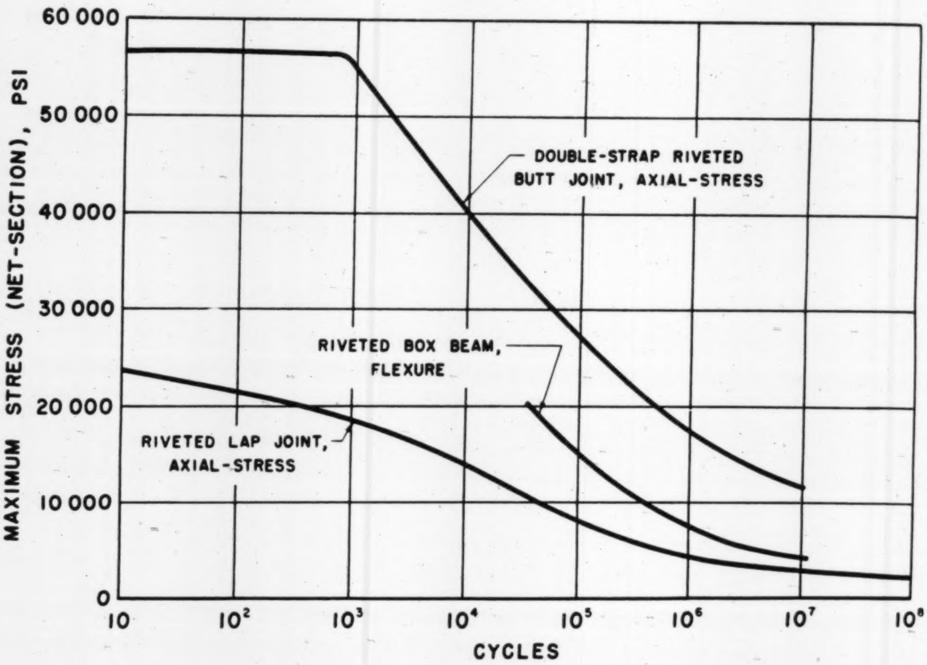


FIG. 18.—Fatigue Curves ($R = -1$) for Various 14S-T6 Specimen Types.

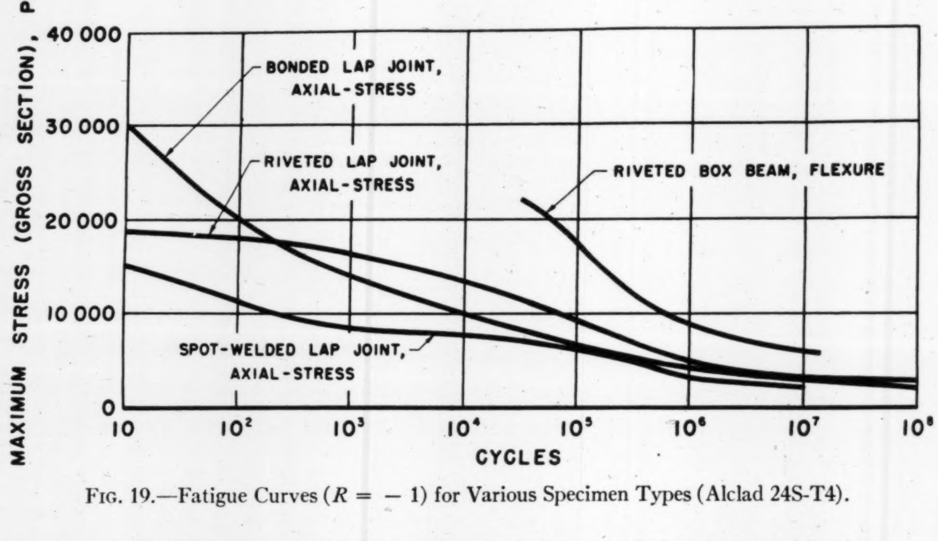


FIG. 19.—Fatigue Curves ($R = -1$) for Various Specimen Types (Alclad 24S-T4).

of some of the factors, such as alloy and surface finish, known to influence appreciably the data from tests of simple smooth specimens. These stress raisers include open holes, holes with rivets or bolts, screw threads, rough sheared edges, and abrupt changes in section, to mention only a few examples. The effects of such factors are illustrated in Fig. 17 where the band of results includes the majority of the test results for eight plate-fastener combinations. Study of the data reveals that little if any consistent relationship exists between static and fatigue strengths at lives exceeding 10^6 cycles. The 3S-H14 riveted joints, which have low static strengths, have fatigue strengths, beyond about 10^6 cycles, equivalent to those of joints with over twice the static strength.

The various types of specimens used in component tests have significant effects on the fatigue values, as noted for the different simple specimen types. The results shown in Figs. 18 and 19 illustrate this observation.

As in the case of simple notch fatigue tests, there is a lack of significant differences in the fatigue strengths of the joints of the various alloys. This is illustrated in Figs. 17 and 20. The absence of any significant differences for 10^6 or more cycles in the welded joints of the aluminum alloys shown in Fig. 20 is interesting because of the marked differences in tensile properties of the alloys. The tensile strengths apparently influence the fatigue strengths markedly for repetitions of load up to about 10^3 or 10^4 times.

The improvements in fatigue strength that frequently can be accomplished by design changes are indeed significant. Figure 21 illustrates one instance of a bolted joint made from a high-strength wrought aluminum alloy. Changes in the design details of aluminum sand castings, however, may cause only slight differences in their fatigue strength, as shown in Fig. 22.

Different procedures used in fabrication may result in significant variations in the fatigue strength of structures, as shown in Fig. 23. Many other details of fabrication practices could be cited which have pronounced effects on the fatigue behavior of structures. Some of these are initial loads on bolts and tie rods, warpage of welded parts, undesirable internal stresses resulting from misfits and thermal treatments, unfilled rivet holes, and omission of fillets or corner chamfers.

The method used in presenting results from fatigue tests of structural components may affect conclusions drawn concerning the merits of various fabrication procedures. Different treatments of the fatigue data shown in Fig. 24 are presented as an example. Two specimen types, one a riveted double-strap butt joint and the other a welded butt joint of 61S-T6 aluminum alloy, are used for the illustration. The following relationships exist between the riveted and welded joints:

	Welded	Riveted
Width, in.	5.0	7.5
Thickness, in.	0.375	0.250
Gross area, sq in.	1.875	1.875
Net area, sq in.	1.875	1.234

Consideration of the total loads on the joints, shown in Fig. 24, indicates no differences in fatigue strengths for 10^4 cycles or more between the riveted and welded joints. For the lower cycles, the riveted joint is superior. On the basis of load per inch of width, the welded joint is significantly better throughout the entire range of cycles. When net stress is used as a basis for comparison, the riveted joint shows the better fatigue strengths for various cycles up to about 10^7. Plotting the data on the basis of

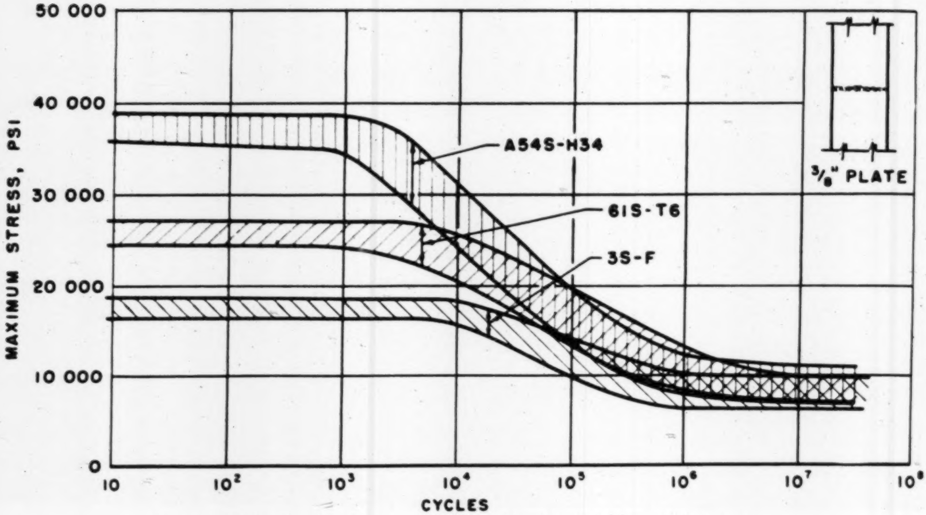
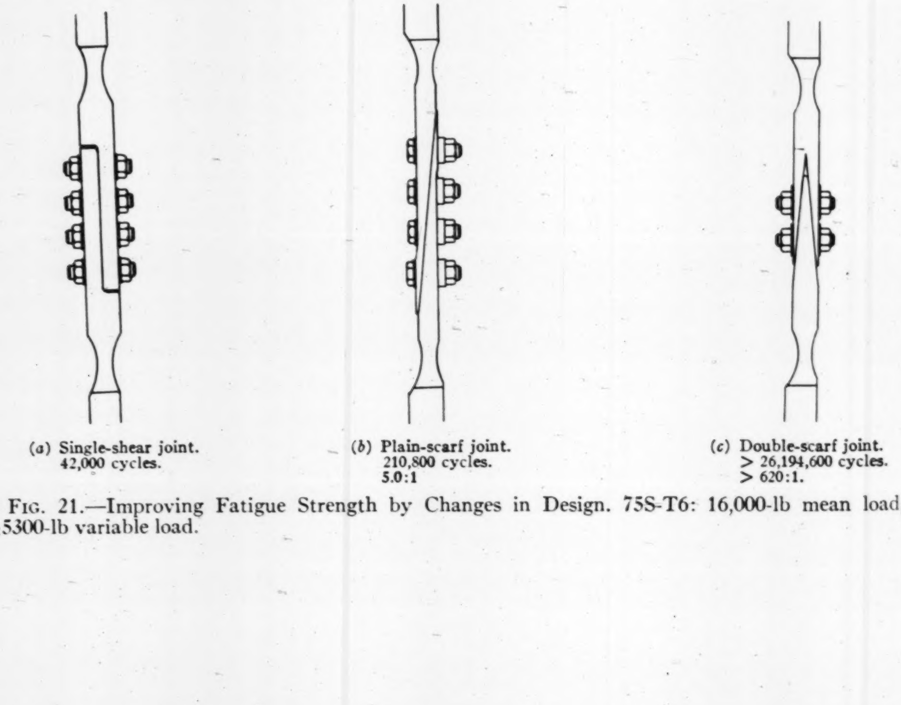


FIG. 20.—Fatigue Strength ($R = 0$) of Welded Butt Joints.


(a) Single-shear joint. 42,000 cycles.

(b) Plain-scarf joint. 210,800 cycles. 5.0:1

(c) Double-scarf joint. > 26,194,600 cycles. > 620:1.

FIG. 21.—Improving Fatigue Strength by Changes in Design. 75S-T6: 16,000-lb mean load, ±5300-lb variable load.

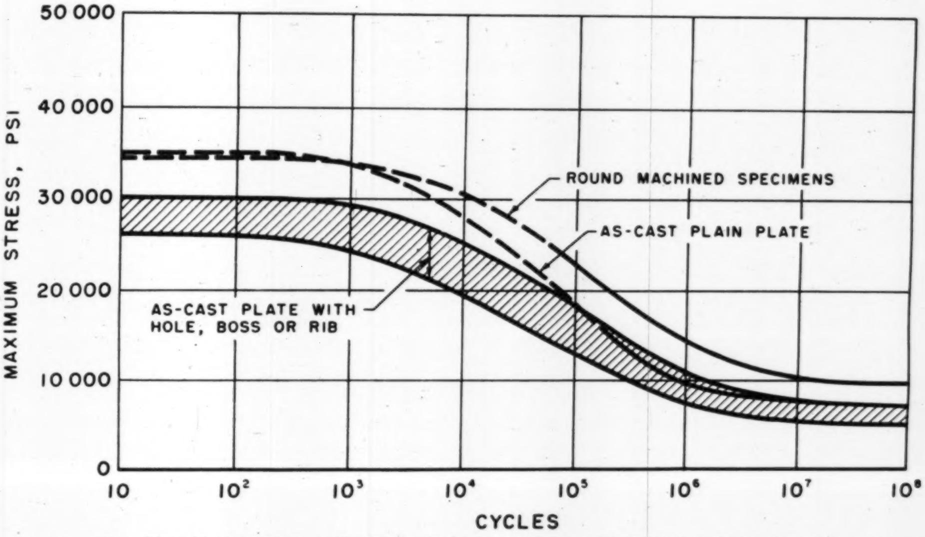


FIG. 22.—Fatigue Strengths ($R = 0$) for Specimens of 355-T6 Sand Castings.

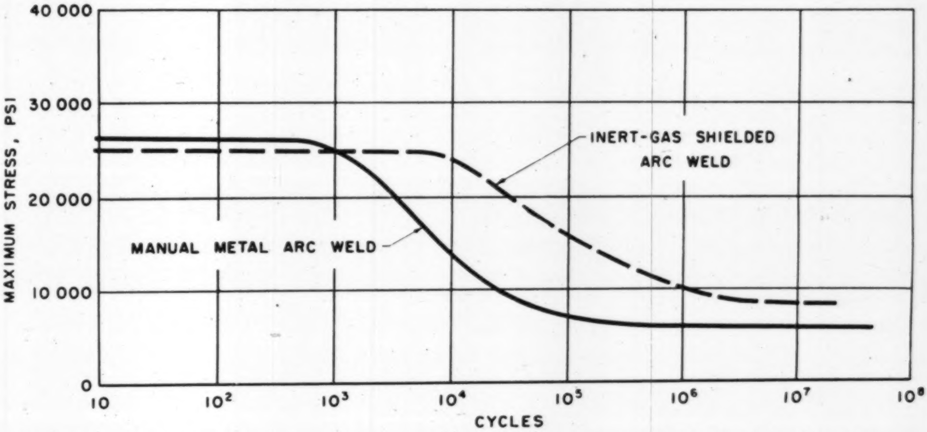


FIG. 23.—Effect of Fabrication on Fatigue Strength ($R = 0$) of 61S-T6 Welded Butt Joints.

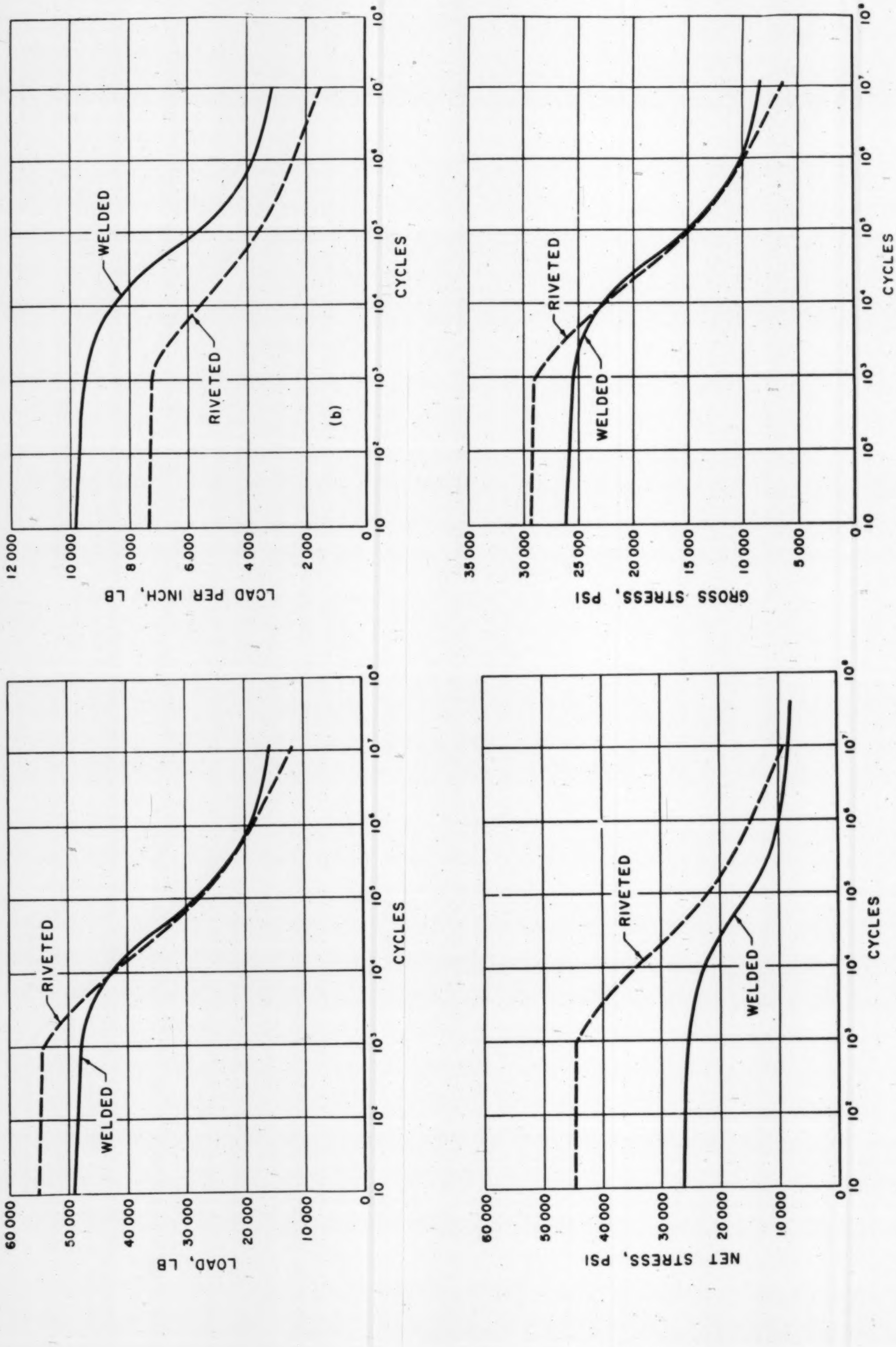


FIG. 24.—Various Methods of Presenting Results of Fatigue Tests of Butt Joints.

gross-area stress, Fig. 24 gives the same relationships as those using a total load basis because the gross areas are equal. This example is intended to emphasize the importance of the methods used in interpreting fatigue results.

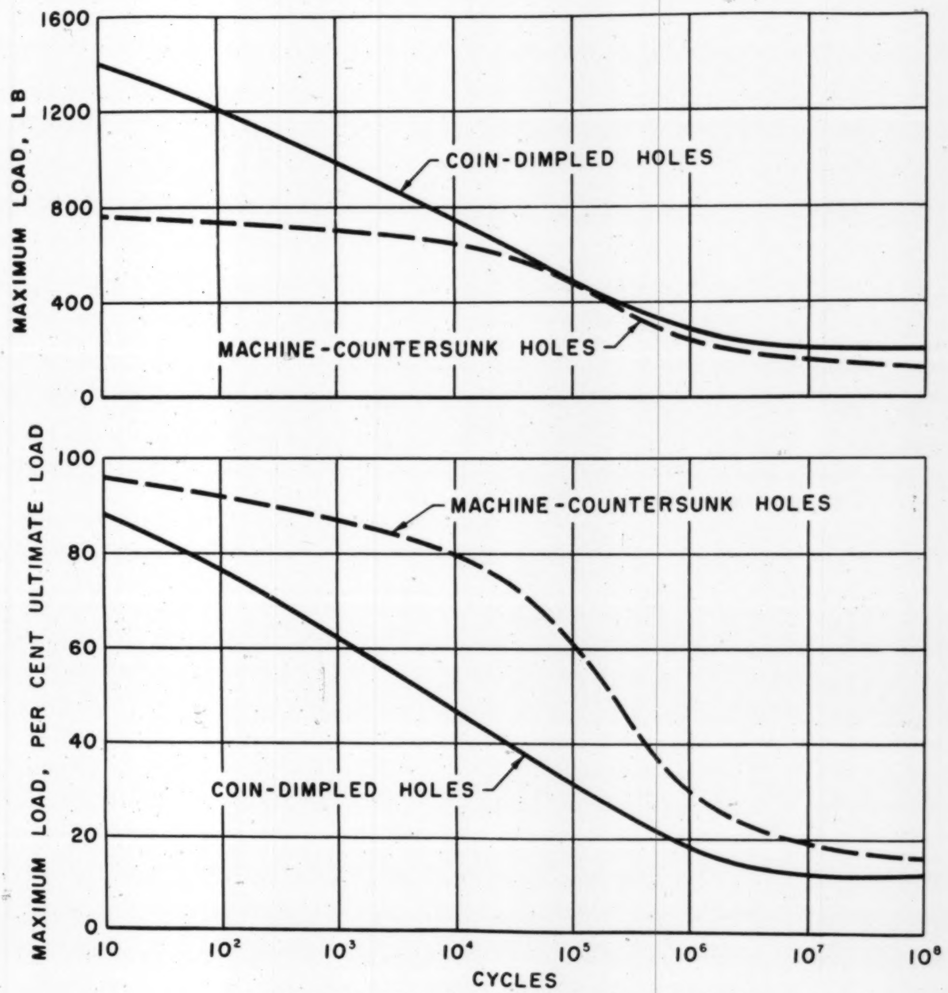


FIG. 25.—Two Methods of Plotting Fatigue Test Results.

Another method often used in presenting fatigue test data is to plot percentage of ultimate static load or percentage of design load against number of cycles to failure. Such a practice can give misleading comparative results since large differences in ultimate load-carrying capacity may not be accompanied by increased fatigue strengths. Such a comparison is shown in Fig. 25 where increased ultimate load-carrying capacity was obtained by changing the method of preparing the rivet holes.

Given typical fatigue data for a specific material and similar data for structural components of the material, fatigue strength reduction factors can be determined for various cycles of repeated loads. Such reduction factors should be helpful to the designers of structures where the configuration details approximate closely those of the components tested. Calculations of theoretical stress concentrations frequently do not give results in agreement with experimentally determined reduction factors. Some results illustrating this fact are given in Figs. 16 and 26.

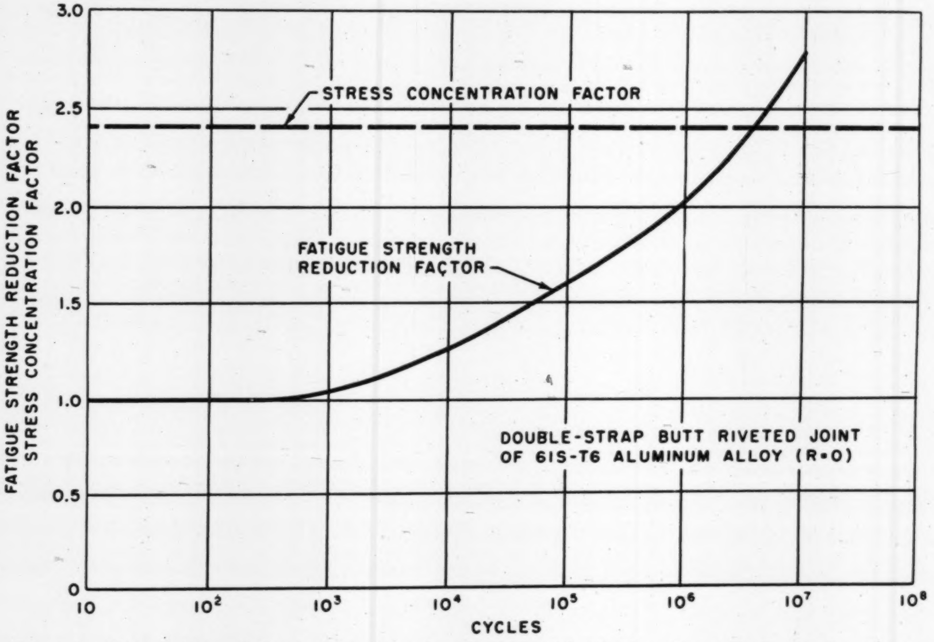


FIG. 26.—Comparison of Stress Concentration Factor with Fatigue Strength Reduction Factor.

Table III presents a number of the fatigue strength reduction factors for some components made of different aluminum alloys. These data may be compared with those previously given for simple notch specimens, and also with those shown in Table IV which have been obtained from fatigue tests of large components or essentially complete aircraft (**489**).

A summary of all available data on the fatigue strength of aluminum alloy riveted joints indicates that, in general, for a single row of rivets, lap joints have about half the fatigue strength of double-strap butt joints. The optimum spacing of rivets for long life appears to be the smallest spacing applicable from a shop standpoint—namely, about three times the rivet diameter or perhaps a little less. For smaller numbers of cycles, the optimum spacing appears to be larger. High tensile strength steel bolts and properly proportioned flush-head rivets appear to function as well as protruding-head rivets, as far as tensile fatigue strengths of the joints are concerned. Hot-driven aluminum alloy rivets are as good as cold-driven aluminum alloy rivets in this respect.

Tests of aluminum alloy double-strap riveted butt joints, in which mismatched rivet holes were simulated by reaming the holes and inserting pins while the specimen was under load, indicate that

TABLE III.—FATIGUE STRENGTH REDUCTION FACTORS FOR STRUCTURAL COMPONENTS.

Alloy and Temper	Specimen Description	Stress Ratio, R	Fatigue Strength Reduction Factors[a]							
			Based on Net-Section Stresses at				Based on Gross-Section Stresses at			
			10^3 cycles	10^5 cycles	10^6 cycles	10^7 cycles	10^3 cycles	10^5 cycles	10^6 cycles	10^7 cycles
14S-T6	Single open hole—monobloc	0	1½	3	3	3	1½	3	3½	3½
14S-T6 75S-T6	Two open holes—monobloc	0	...	2	2	...	...	3	3	...
355-T6	Single open hole—monobloc	0	1½	1½	2	2	1½	2	2	2
Alclad 14S-T6 Alclad 24S-T3 Alclad 75S-T6	Riveted lap joint—sheet	−1	3½	3½	4½	6½	4½	4½	6	8
14S-T6	Riveted lap joint—plate	0	2½	3	5	10	3½	4	8	14
14S-T6	Riveted double-strap butt joint	0	1½	2	2	3½	2	3	4	5
61S-T6	Welded plain-butt joint	0	...	3	3	...	...	4	4	...
75S-T6	Bolted plain-scarf joint	0	1½	2	2½	3	1½	2	2½	3
Alclad 14S-T6 Alclad 24S-T3 Alclad 75S-T6	Riveted box beams	−1	...	2½	3½	4	...	2½	3½	4

[a] Fatigue strength reduction factor $= \frac{\text{maximum stress for smooth specimen}}{\text{maximum stress for test specimen}}$ (at same stress ratio and lifetime).

TABLE IV.—FATIGUE STRENGTH REDUCTION FACTORS FOR TRANSPORT-AIRPLANE WING FAILURES.[a]

Load Ratio, R	Fatigue Strength Reduction Factors[b]				
	Corner of Inspection Cutout	Riveted Tension Joint	Riveted Shear Joint	Cutout Reinforcement	Miscellaneous Discontinuities
0.481	...	...	...	5.0–5.4	3.0–4.0
0.403	4.6–5.2	...	3.0	4.0–5.6	2.6–3.9
0.231	3.8–4.6	2.2–2.4	3.0–3.7	3.8–4.1	3.2–5.2
0	3.2–4.1	...	...	3.4–4.6	2.2–4.3

[a] Results from *Technical Note No. 3190*, Nat. Advisory Comm. Aeronautics, 1954.

[b] Fatigue strength reduction factor $= \frac{\text{maximum stress for smooth specimen}}{\text{maximum measured stress near stress raiser of test specimen}}$ (at same load ratio and lifetime).

the stresses introduced by such fabrication cause an appreciable reduction in fatigue strength. Static preloading of a joint with simulated mismatched rivet holes to 88 per cent of net-section yield strength improved the fatigue strength of the joint but not enough to equal that of a joint without mismatch. These facts are presented in Fig. 27. On the other hand, static preloading of carefully fabricated riveted joints up to about 90 per cent of their ultimate tensile strengths (about equal to the net-section yield strength) has not shown any significant improvement in fatigue strength, although there is some evidence that higher preloads may be beneficial to the fatigue life of such a joint.

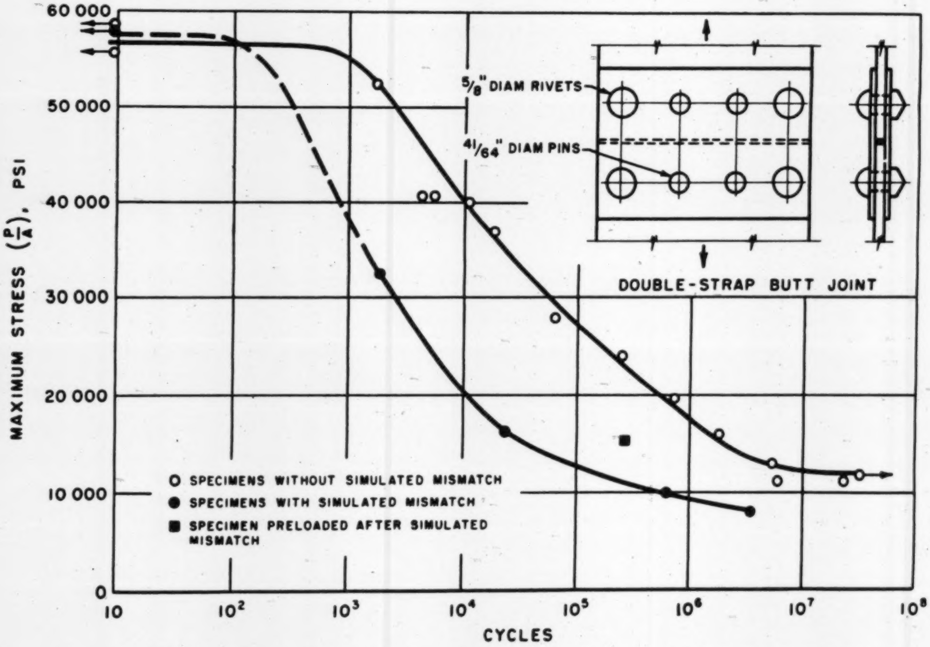


FIG. 27.—Effect of Mismatch on Fatigue Strength ($R = 0$) of 14S-T6 Riveted Joints.

The remarks just made concerning riveted joints of aluminum are believed typical of the information that can be obtained from fatigue tests of structural components. It is known that most of the major aircraft manufacturers have made some fatigue tests of components, although many of the results from these tests have not been published. If this information could be summarized and made available, it should be useful to designers in improving the lives of aircraft.

Several investigators have reported the results of fatigue tests of actual structures (**290,402,405,422,423,461,465**). For those cases in which comparisons can be made on the basis of stress rather than percentage of ultimate or design load, reasonable agreement is found between the results of component tests and structural tests.

SUMMARY

The investigational work on the fatigue properties of aluminum alloys that has been going on continuously during the past 35 years has provided extensive information on the behavior of these alloys under conditions of repeated stress. The data available, however, are not of sufficient scope to answer all the fatigue problems that have occurred. A better knowledge of states of combined stress, repeated shear stresses, and various stress-raiser configurations—all at both room and elevated temperatures—is needed.

Much progress is now being made toward a better understanding of the fundamental mechanism of the fatigue phenomena in metals, particularly for aluminum. It is expected that this knowledge will be helpful in efforts to improve the fatigue strengths of metals.

Although the simple smooth and notch-type laboratory fatigue specimens give useful information, results from them are not directly applicable by designers in most instances.

Much progress has been made in evaluating the fatigue properties of aluminum-alloy structural components, the relative merits of different geometric configurations, and fabrication procedures, but the problems in this category are legion.

Some expensive fatigue tests have been made on actual structures with rather gratifying results. Reasonable correlation between the component and complete structure test data has been found, but closer agreement is desired.

Much better correlation of all the various kinds of accelerated fatigue tests with actual service behavior of machines and structures is desired. This apparently will require many years. Meanwhile, fatigue strengths of structures and their components can be improved in many instances by use of the information from comparisons of different designs of components. This appears to be a valid conclusion irrespective of whether aluminum or other metals are used.

Acknowledgment:

In closing, I want to express appreciation of and acknowledge the generous assistance given by fellow members of the Aluminum Research Laboratories. The contributions of F. M. Howell, Chief of the Mechanical Testing Division, E. C. Hartmann, Chief of the Engineering Design Division, and Messrs. Holt, Lyst, Eaton, and Miss Vera Funk are deserving of particular mention.

BIBLIOGRAPHY

1899

(1) J. A. Ewing and W. Rosenhain, "Experiments in Micro-Metallurgy: Effects of Strain. Preliminary Notice," *Proceedings*, Royal Soc. (London), Vol. 65, p. 85.

1903

(2) J. A. Ewing and J. C. W. Humphrey, "The Fracture of Metals Under Repeated Alternations of Stress," *Transactions*, Royal Soc. (London), Series A, Vol. 200, Part I, p. 241.

1907

(3) Henry Souther, "White-Souther Endurance Test Specimen," *Proceedings*, Am. Soc. Testing Mats., Vol. 7, p. 616.

1910

(4) W. Rosenhain and F. C. A. H. Lantsberry, "Ninth Report to the Alloys Research Committee of The Institution of Mechanical Engineers (British) on the Properties of Some Alloys of Copper, Aluminum, and Manganese," Nat. Physics Lab.

1917

(5) G. A. Hankins, "Alternating Stress Tests of Aluminum Alloys," *Report No. 12*, Advisory Comm. for Aeronautics, Light-Alloys Subcommittee.

1919

(6) F. C. Lea, "Aluminum Alloys for Aeroplane Engines," Lecture to Royal Aeronautical Soc. (British) (April 16).

(7) P. D. Merica and C. P. Karr, "Some Tests of Light Aluminum Casting Alloys. The Effect of Heat Treatment," *Proceedings*, Am. Soc. Testing Mats., Vol. 19, Part II, p. 297.

1920

(8) W. A. Gibson, "Fatigue and Impact Fatigue Tests of Aluminum Alloys," *Proceedings*, Am. Soc. Testing Mats., Vol. 20, Part II, p. 115.

(9) C. F. Jenkin, "Report on Materials of Construction Used in Aircraft and Aircraft Engines," H. M. Stationery Office (British), p. 80.

(10) R. W. Woodward, "Recent Developments in Light Alloys," *Technical Memo No. 3*, Nat. Advisory Comm. Aeronautics.

1921

(11) Anon., "Fatigue and Duralumin," *Aviation*, Vol. 10, p. 39.

(12) Walter Rosenhain, Sydney L. Archbutt, and D. Hanson, "Eleventh Report to the Alloys Research Committee of The Institution of Mechanical Engineers (British) on Some Alloys of Aluminum," Nat. Physics Lab.

1922

(13) Anon., "Fatigue Resistance of Duralumin," *Technical Memo No. 135*, Nat. Advisory Comm. Aeronautics.

(14) Richard L. Templin, "Present Status of the Knowledge of the Fatigue Strength of Some Aluminum and Magnesium Alloys," *Iron Age*, Vol. 110, p. 356.

1923

(15) H. J. Gough and D. Hanson, "The Behaviour of Metals Subjected to Repeated Stresses," *Proceedings*, Royal Soc. (London), Series A, Vol. 104, p. 538.

(16) R. R. Moore, "Resistance of Manganese Bronze, Duralumin, and Electron Metal to Alternating Stresses," *Proceedings*, Am. Soc. Testing Mats., Vol. 23, Part II, p. 106.

1924

(17) H. J. Gough, "The Fatigue of Metals," Scott, Greenwood & Son (London).

(18) D. J. McAdam, Jr., "Accelerated Fatigue Tests and Some Endurance Properties of Metals," *Proceedings*, Am. Soc. Testing Mats., Vol. 24, Part II, p. 454.

1925

(19) R. R. Moore, "Some Fatigue Tests on Non-Ferrous Metals," *Proceedings*, Am. Soc. Testing Mats., Vol. 25, Part II, p. 66.

1926

(20) Anon., "Aluminum Silicon Alloys," *Automotive Industries*, Vol. 55, No. 20, p. 825.

(21) H. J. Gough, D. Hanson, and S. J. Wright, "The Behavior of Single Crystals of Aluminum Under Static and Repeated Stresses," *Transactions*, Royal Soc. (London), Series A, Vol. 226, p. 1.

(22) H. J. Gough, S. J. Wright, and D. Hanson, "Further Experiments on Single Crystals of Aluminum Employing Reversed Direct Stresses," *Report and Memo No. 1024*, Aeronautical Research Comm. (British).

(23) R. R. Moore, "Effect of Grooves, Threads, and Corrosion Upon the Fatigue of Metals," *Proceedings*, Am. Soc. Testing Mats., Vol. 26, Part II, p. 255.

1927

(24) D. J. McAdam, Jr., "Corrosion-Fatigue of Non-Ferrous Metals," *Proceedings*, Am. Soc. Testing Mats., Vol. 27, Part II, p. 102.

(25) D. J. McAdam, Jr., "Fatigue and Corrosion-Fatigue of Metals," *Proceedings*, Internat. Congress Testing Materials, Vol. I, p. 305.

(26) H. F. Moore, "Fatigue of Metals," *Proceedings*, Internat. Congress Testing Materials, Vol. I, p. 297.

(27) H. F. Moore and J. B. Kommers, "The Fatigue of Metals," McGraw-Hill Book Co., Inc.

(28) R. R. Moore, "Effect of Corrosion Upon the Fatigue Resistance of Thin Duralumin," *Proceedings*, Am. Soc. Testing Mats., Vol. 27, Part II, p. 128.

1928

(29) D. J. McAdam, Jr., "Some Factors Involved in Corrosion and Corrosion-Fatigue of Metals," *Proceedings*, Am. Soc. Testing Mats., Vol. 28, Part II, p. 117.

(30) S. S. Nekryty and I. I. Bokov, "Fatigue of Castings of Light Aluminum Alloys Subjected to Repeatedly Reversed Stres-

ses," *Festnik Inginieurov* (Moscow), Nos. 5 and 6, p. 245; *Transactions*, Am. Soc. Steel Treating, Vol. 14, p. 941.

(31) Von Dr. Ing. Richard Wagner, "Results of Fatigue Tests on Aluminum and Magnesium Alloys," Verlag von Julius, Berlin.

1929

(32) J. B. Johnson and T. T. Oberg, "Fatigue Resistance of Some Aluminum Alloys," *Proceedings*, Am. Soc. Testing Mats., Vol. 29, Part II, p. 339.

(33) D. J. McAdam, Jr., "Corrosion of Metals Under Cyclic Stress," *Proceedings*, Am. Soc. Testing Mats., Vol. 29, Part II, p. 250.

1930

(34) Anon., "Fatigue of Aluminum Alloys," *Metallurgist* (Supplement to *Engineer*), No. 137.

(35) D. J. McAdam, Jr., "The Influence of Stress Range and Cycle Frequency on Corrosion," *Proceedings*, Am. Soc. Testing Mats., Vol. 30, Part II, p. 411.

(36) H. F. Moore and T. Ver, "A Study of Slip Lines, Strain Lines, and Cracks in Metals Under Repeated Stress," *Bulletin No. 208*, University of Illinois Engineering Experiment Station.

(37) R. L. Templin, "Detection of Incipient Fatigue Failures," *Proceedings*, Am. Soc. Testing Mats., Vol. 30, Part II, p. 289.

1931

(38) H. W. Gillett, "What Is This Thing Called Fatigue," *Metals & Alloys*, Vol. 2, p. 71.

(39) D. Hanson and M. A. Wheeler, "The Deformation of Metals Under Prolonged Loading," *Proceedings*, Inst. of Metals (British), Vol. 45, p. 229.

(40) H. F. Moore and R. E. Lewis, "Fatigue Tests in Shear of Three Non-Ferrous Metals," *Proceedings*, Am. Soc. Testing Mats., Vol. 31, Part II, p. 236.

(41) R. L. Templin, "Fittings Control the Life of Metallic Tubing Subjected to Vibration," *Automotive Industries*, Vol. 65, p. 50.

1932

(42) R. Cazaud, "Investigations on the Fatigue of Metals," *Chimie et Industrie* (Special Number), p. 390; *Chemical Abstracts*, Vol. 26, p. 3464; *Metallurgical Abstracts*, Vol. L, No. 3.

(43) R. Cazaud, "Resistance to Fatigue of Some Aluminum Casting Alloys," *Bulletin*, Assoc. Tech. Fonderie, Vol. 6, p. 485.

(44) H. J. Gough and D. G. Sopwith, "Atmospheric Action as a Factor in Fatigue of Metals," Inst. Mechanical Engrs. (London).

(45) R. Irmann, "Fatigue Limits of Aluminum Alloys," Internat. Foundry Congress (Paris).

(46) J. B. Kommers, "Understressing and Notch Sensitiveness in Fatigue," *Engineering News-Record*, Vol. 109, p. 353.

(47) P. Ludwik, "Fatigue Strength and Resistance to Slip," *Metal Industry* (London), Vol. 41, p. 613.

(48) R. A. Monroe and R. L. Templin, "Vibration of Overhead Transmission Lines," *Transactions*, Am. Inst. Electrical Engrs., Vol. 51, p. 1059.

(49) W. Saran, "The Static and Fatigue Strength of Light Metal Sand Castings," *Zeitschrift für Metallkunde*, Vol. 24, p. 181.

1933

(50) Anon., "Fatigue Phenomena Exhibited by Large Single Metallic Crystals," Nat. Physics Lab., p. 147.

(51) R. Cazaud, "Fatigue Resistance of Some Casting Alloys of Aluminum," *Revue de métallurgie*, Vol. 30, p. 385; *Chemical Abstracts*, Vol. 28, p. 3699 (1934).

(52) J. W. Cuthbertson, "The Fatigue Resisting Properties of Light Aluminum Alloys at Elevated Temperatures," *Engineering*, Vol. 135, p. 342; *Journal*, Inst. Metals, Vol. 51, p. 163.

(53) H. J. Gough, "Crystalline Structures in Relation to Failure of Metals—Especially by Fatigue," Edgar Marburg Lecture, *Proceedings*, Am. Soc. Testing Mats., Vol. 33, Part II, p. 3.

(54) H. J. Gough and D. G. Sopwith, "Some Comparative Corrosion-Fatigue Tests Employing Two Types of Stressing Action," *Engineering*, Vol. 136, p. 75; *Journal*, Iron and Steel Inst. (London), No. 1.

(55) R. L. Templin, "The Fatigue Properties of Light Metals and Alloys," *Proceedings*, Am. Soc. Testing Mats., Vol. 33, Part II, p. 364.

1934

(56) R. Cazaud, "Metal Fatigue and Methods for Its Measurement," *Journal*, Aeronautical Sci., Vol. 1, p. 137.

(57) R. Cazaud, "Influence of Corrosion on the Fatigue Resistance of Duralumin," *Revue de métallurgie*, Vol. 31, p. 440.

(58) Mlle. L. Doussin, "A Study of Fatigue of Weldments of Mild Steel and Cr-Mo Steel Used in Aircraft Construction," *Bulletin No. 28* de la Ste des Ingenieures-Sondeurs.

(59) G. N. Krouse, "A High-Speed Fatigue Testing Machine and Some Tests of Speed Effect on Endurance Limit," *Proceedings*, Am. Soc. Testing Mats., Vol. 34, Part II, p. 156.

(60) W. Linicus and E. Scheuer, "Fatigue Properties of Light Cast Metals," *Metall-Wirtschaft-Wissenschaft-Technik*, XII Nr. 47, p. 829; Nr. 48, p. 849; *Light Metals Research*, Vol. 3, p. 365 (1935); *Journal*, Inst. Metals, Vol. 2, p. 281 (1935).

(61) K. Matthaes, "Fatigue Strength of Airplane and Engine Materials," *Technical Memo No. 743*, Nat. Advisory Comm. Aeronautics; *Zeitschrift für Flugtechnik und Motorluftschiffart*, Vol. 24, p. 593.

(62) D. J. McAdam, Jr., and R. W. Clyne, "Influence of Chemically and Mechanically Formed Notches on Fatigue of Metals," *Journal of Research*, Nat. Bureau Standards, Vol. 13, p. 527.

(63) P. D. Morgan and E. W. W. Double, "Effects of Working Tension and Lay Ratio Upon the Fatigue Failure of Steel-Cored Aluminum Conductor," *Technical Report F.T76*, British Electrical and Allied Industries Research Assn.

(64) H. A. Smith, "Fatigue and Crystal Recovery in Aluminum," *Physics*, Vol. 5, p. 412.

(65) H. Sutton and W. J. Taylor, "The Influence of Pickling on the Fatigue Strength of Duralumin," *Journal*, Inst. Metals, Vol. LV, No. 2, p. 149.

1935

(66) Anon., "Corrosion-Fatigue Properties of Duralumin," *Engineering*, Vol. 139, p. 289.

(67) W. D. Boone and H. B. Wishart, "High-Speed Fatigue Tests of Several Ferrous and Non-Ferrous Metals at Low Temperatures," *Proceedings*, Am. Soc. Testing Mats., Vol. 35, Part II, p. 147.

(68) H. L. Cox and W. J. Clenshaw, "Behavior of Three Single Crystals of Aluminum in Fatigue Under Complex Stresses," *Proceedings*, Royal Soc. (London), Series A, Vol. 149, p. 312.

(69) I. J. Gerard and H. Sutton, "Corrosion-Fatigue Properties of Duralumin with and Without Protective Coatings," *Journal*, Inst. Metals, Vol. 56, No. 1, p. 29.

(70) H. J. Gough and W. J. Clenshaw, "The Testing of Engineering Materials," *Transactions*, Inst. Marine Engrs., Vol. 57, Part 10.

(71) Otto Graf, "On Tensile Fatigue Tests with Flat Bars and Riveted Joints of Light Metal," *Der Stahlbau*, Vol. 8, p. 132.

(72) R. Irmann, "Fatigue Strength of Aluminum Alloys," *Aluminium*, Vol. 17, p. 638; *Congrès international des mines, de la métallurgie et de la géologie appliquée*, Vol. 1, p. 435; *Revue de métallurgie*, Vol. 33, p. 231 (1936).

(73) A. von Zeerleder, "On the Development of Fatigue Tests of Aluminum and Its Light Alloys," *Alluminio*, Vol. 4, p. 95; *Metallurgical Abstracts*, Vol. 3, p. 700 (1936).

(74) A. von Zeerleder, "General Review of Methods of Investigation in Determining the Fatigue Properties of Aluminum Castings," *Aluminium*, Vol. 17, p. 570; *Congrès international des mines, de la métallurgie et de la géologie appliquée*, Vol. 1, p. 299; *Light Metals Review*, Vol. 2, p. 256 (1936).

1936

(75) H. Bohner, "Influence of Deformation and the Thermal Treatment on the Resistance to Fatigue of Heat Treatable Aluminum Alloys," *Metallwirtschaft*, Vol. 15, p. 813.

(76) H. Bohner, "The Fatigue Impact Strength of Heat-Treated Aluminum Alloys," *Metallwirtschaft*, Vol. 15, p. 983; *Light Metals Research*, Vol. 5, p. 134.

(77) G. Euringer, "The Bending Fatigue of Duralumin at 350 C," *Metallwirtschaft*, Vol. 15, p. 540; *Chemical Abstracts*, Vol. 30, p. 7522.

(78) F. H. Frankland, H. D. Johnson, and R. L. Templin, "Structural Aluminum and Fatigue," *Engineering News-Record*, Vol. 116, No. 20, p. 709.

(79) H. J. Gough and G. Forrest, "A Study of the Fatigue Characteristics of Three Aluminum Specimens Each Containing from Four to Six Large Crystals," *Journal*, Inst. Metals, Vol. 58, p. 97.

(80) H. J. Gough and W. A. Wood, "A New Attack Upon the Problem of Fatigue of Metals, Using X-ray Methods of Precision," *Proceedings*, Royal Soc. (London), Series A, Vol. 154, p. 510.

(81) H. F. Moore, "How and When Does a Fatigue Crack Start?" *Metals & Alloys*, Vol. 7, p. 297.

1937

(82) C. S. Barrett, "The Application of X-ray Diffraction to the Study of Fatigue in Metals," *Transactions*, Am. Soc. Metals, Vol. 25, p. 1115.

(83) Charles S. Barrett, "Fatigue Failure, the Difficulties of Predicting It by X-rays," Metals Research Lab., Carnegie Institute of Technology (November).

(84) Paul Behrens and Helmut Hutter, "Fatigue Tests with Steel-Aluminum and Hollow Copper Cables for Medium and High Tension Transmission Lines," *Elektrizitatswirtschaft*, Vol. 36, p. 331: *Metallurgical Abstracts*, Vol. 9, p. 371.

(85) F. W. Caldwell, "Vibration Problem in Aircraft Propeller Designing," *Journal*, Soc. Automotive Engrs., Vol. 41, p. 372.

(86) C. H. Greenall and G. R. Gohn, "Fatigue Properties of Non-Ferrous Sheet Metals," *Proceedings*, Am. Soc. Testing Mats., Vol. 37, Part II, p. 160.

(87) F. M. Howell and E. S. Howarth, "A Fatigue Machine for Testing Metals at High Temperatures," *Proceedings*, Am. Soc. Testing Mats., Vol. 37, Part II, p. 206.

(88) T. T. Oberg and J. B. Johnson, "Fatigue Properties of Metals Used in Aircraft Construction at 3450 and 10,600 Cycles," *Proceedings*, Am. Soc. Testing Mats., Vol. 37, Part II, p. 195.

(89) C. Pizzuto, "Duralumin Studied in Relation to the Rotating-beam Endurance Limit," Internat. Assn. Testing Materials Congress (London).

(90) Georges Welter, "Influence of Mechanical Vibration on the Fatigue Properties of Construction Materials," *Zeitschrift für Metallkunde*, Vol. 29, p. 60.

1938

(91) Anon., "Preliminary Fatigue Studies on Aluminum Alloy Aircraft Girders," *Technical Note No. 637*, Nat. Advisory Comm. Aeronautics.

(92) W. N. Bleakney, "Fatigue Testing of Wing Beams by the Resonance Method," *Technical Note No. 660*, Nat. Advisory Comm. Aeronautics.

(93) J. B. Johnson and T. T. Oberg, "Airplane Propeller Blade Life," *Metals & Alloys*, Vol. 8, p. 259.

(94) O. Nissen, "Fatigue in Aeroplane Structures," *Luftfahrt-Forschung*, p. 158; *Aircraft Engineering*, Vol. 12, p. 293 (1940).

(95) E. Ravilly, "Contribution to the Study of the Rupture of Metallic Wires Subjected to Alternating Torsion," *Publications scientifiques et techniques du ministere de l'air* (France), No. 120, p. 52.

(96) E. von Rajakovics, "A Study of the Fatigue Strength of Wrought Aluminum Alloys," *Light Metals Research*, Vol. 6, p. 454.

(97) H. Westhoff, "Endurance Limit of Workable Aluminum Alloys," *Zeitschrift für Metallkunde*, Vol. 30, p. 258; *Journal*, Soc. Chem. Industry, Vol. 57, p. 1438.

(98) E. Wood, "Service Failures of Light Alloys," *Metal Industry*, Vol. 52, p. 121.

1939

(99) K. Arnstein and E. L. Shaw, "Fatigue Problems in the Aircraft Industry," *Metals & Alloys*, Vol. 10, p. 203.

(100) Franz Bollenrath, "Endurance Properties of Some Light Metal Forging Alloys in Various Applications Under Stress: Influence of Cold Working," *Metallwirtschaft*, Vol. 18, p. 2; *Light Metals Research*, Vol. 7, p. 146.

(101) G. Gürtler, W. Jung-König, and E. Schmid, "Fatigue Strengths of Light Metals at Different Temperatures," *Aluminium*, Vol. 21, p. 202; *Metallurgical Abstracts*, Vol. 6, p. 170.

(102) A. V. Karpov, "Fatigue Problems in Structural Designs," *Metals & Alloys*, Vol. 10, p. 346.

(103) J. A. Kies and G. W. Quick, "Effect of Service Stresses on Impact Resistance, X-ray Diffraction Patterns, and Microstructure of 25S Aluminum Alloy," *Report No. 659*, Nat. Advisory Comm. Aeronautics.

(104) W. B. Mechling and S. S. Jack, "Some Mechanical Tests on Aluminum Alloys 14S-T and 24S-T," *Proceedings*, Am. Soc. Testing Mats., Vol. 39, p. 769.

(105) W. Müller, "Influence of the Roughness of the Surface on the Fatigue Strength of Aluminum Alloy Rolled Sheet," *Alluminio*, Vol. 8, p. 76.

(106) E. Orowan, "Theory of the Fatigue of Metals," *Proceedings*, Royal Soc. (London), Series A, Vol. 171, p. 79.

(107) G. Sachs, "Improving Aircraft Propellers by Surface Rolling," *Metals & Alloys*, Vol. 10, p. 19.

(108) R. L. Templin, "Fatigue Testing," *Metals Handbook*, Am. Soc. Metals, p. 143.

(109) R. L. Templin, "Fatigue of Light Metal Alloys," *Metals & Alloys*, Vol. 10, p. 243.

(110) R. L. Templin, "Fatigue Machines for

Testing Structural Units," *Proceedings*, Am. Soc. Testing Mats., Vol. 39, p. 711.

(111) G. A. Tomlinson, P. L. Thorpe, and H. J. Gough, "An Investigation of the Fretting Corrosion of Closely-Fitting Surfaces," *Engineering*, Vol. 147, p. 293; *Engineer*, Vol. 167, p. 315.

1940

(112) N. N. Afanas'ev, "Statistical Theory of the Fatigue of Metals," *Zhurnal Tekhnicheskoĭ Fiziki* (Journal of Technical Physics, USSR), Vol. 10, p. 1553; *Chemical Abstracts*, Vol. 35, p. 6907 (1941); *Metallurgical Abstracts*, Vol. 9, p. 35 (1942).

(113) F. Bollenrath, "Factors Influencing the Fatigue Strength of Materials," *Luftfahrt-Forschung*, Vol. 17, No. 10, p. 320; *Technical Memo No. 987*, Nat. Advisory Comm. Aeronautics.

(114) F. Bollenrath and H. Cornelius, "The Effect of Rest Periods on the Time and Fatigue Strength of Metallic Materials," *Zeitschrift des Vereines deutscher Ingenieure*, Vol. 134, p. 295; The David W. Taylor Model Basin, Bureau of Ships, Navy Dept., Translation No. 104 (by F. A. Raven) (1942).

(115) F. Bollenrath and H. Cornelius, "Endurance and Fatigue Strength of Machine Parts of Simple Design," *Zeitschrift des Vereines deutscher Ingenieure*, Vol. 84, p. 407.

(116) G. Forrest, "Fatigue, With Reference to Wrought Aluminum Alloys," *Metallurgia*, Vol. 22, p. 51.

(117) G. Gürtler, "Investigations Regarding the 'Damage Line' in Fatigue Tests on Light Metals," *Zeitschrift für Metallkunde*, Vol. 32, p. 21; *Light Metals Bulletin*, Vol. 1, p. 420.

(118) E. Hottenrott, "The Endurance Strength of Aluminum Sheets," *Luftfahrt-Forschung*, Vol. 17, p. 247.

(119) I. Iganasi and H. Seikito, "Fatigue Tests of Light Alloy Sheets," *Transactions*, Soc. Mechanical Engrs. (Japan), Vol. 6, No. 22, p. 2; *Journal*, Inst. Metals, Vol. 7, p. 394.

(120) K. R. Jackson, "Modern Aircraft Materials and Their Testing," *Journal*, Soc. Automotive Engrs., Vol. 47, No. 5, p. 461.

(121) George Sachs, "Fatigue Failure," *Iron Age*, Vol. 146, p. 31.

(122) E. von Rajakovics, "Fatigue Tests on Aluminum Alloys," *Metallwirtschaft*, Vol. 19, p. 929; *Journal*, Inst. Metals, Vol. 10, p. 315.

(123) J. L. Zambrow and M. G. Fontana, "Mechanical Properties, Including Fatigue, of Aircraft Alloys at Very Low Temperatures," *Transactions*, Am. Soc. Mechanical Engrs., Vol. 41, p. 480.

1941

(124) Anon., "Prevention of the Failure of Metals Under Repeated Stress," John Wiley and Sons Co., Inc.

(125) A. Beerwald, "Chromium-Plated Duralumin," *Luftfahrt-Forschung*, Vol. 18, p. 368; *Sheet Metal Industries*, Vol. 16, p. 1889; Vol. 17, p. 68.

(126) F. Bollenrath and W. Bungardt, "Corrosion Fatigue of Some Aluminum Alloys Through the Action of Hot Liquids," *Luftfahrt-Forschung*, Vol. 18, p. 417; *Chemical Abstracts*, Vol. 37, p. 4354.

(127) R. M. Brick and Arthur Phillips, "Fatigue and Damping Studies of Aircraft Sheet Materials; Duralumin Alloy 24S-T, Alclad 24S-T and Several 18-8 Type Stainless Steels," *Transactions*, Am. Soc. Metals, Vol. 29, No. 2, p. 435.

(128) H. Bürnheim, "Fatigue Strength of Lug-Ends of High-Strength Aluminum-Copper-Magnesium Alloys," *Aluminium*, Vol. 23, p. 208; *Journal*, Inst. Metals, Vol. 8, p. 294.

(129) H. Bürnheim, "Effect of Threaded and Serrated Holes on the Limited Time and Fatigue Strength of Flat Light-Alloy Strips," *Luftfahrt-Forschung*, Vol. 18, p. 102; *Technical Memo No. 994*, Nat. Advisory Comm. Aeronautics.

(130) E. C. Hartmann, "Fatigue Test Results—Their Use in Design Calculations," *Product Engineering*, Vol. 12, p. 74.

(131) E. C. Hartmann and R. L. Templin, "Fatigue Data Used in Design," *Metal Progress*, Vol. 39, p. 604.

(132) H. Guilford Hoskins, "Fatigue Tests on Duralumin," *Aircraft Engineering*, Vol. 13, p. 132; *Journal*, Inst. Metals, Vol. 9, p. 108.

(133) H. W. Kaul, "Statistical Analysis of the Time and Fatigue Strength of Aircraft Wing Structures," *Technical Memo No. 992*, Nat. Advisory Comm. Aeronautics.

(134) W. Mauksch, "The Alternate-Bending Fatigue Strength of Anodized Aluminum Alloys," *Aluminium*, Vol. 33, p. 285; *Light Metals Bulletin*, Vol. 4, p. 232.

(135) H. F. Moore, "Effect of Type of Testing Machine on Fatigue Test Results," *Pro-*

ceedings, Am. Soc. Testing Mats., Vol. 51, p. 133.

(136) A. Ono, "Fatigue Tests on Iron, Steel, and on a Light Alloy Chiefly Under Bending," *Metallurgical Abstracts*, Vol. 8, p. 135.

(137) G. Sachs and P. Stefan, "Chafing Fatigue Strength of Some Metals and Alloys," *Transactions*, Am. Soc. Metals, Vol. 29, No. 2, p. 373.

(138) Raymond G. Spencer and J. Wallace Marshall, "An X-ray Study of the Changes That Occur in Aluminum During the Process of Fatiguing," *Journal of Applied Physics*, Vol. 12, No. 3, p. 191.

(139) G. W. Stickley, "Effect of Alternately High and Low Repeated Stresses Upon the Fatigue Strength of 25S-T Aluminum Alloy," *Technical Note No. 792*, Nat. Advisory Comm. Aeronautics.

(140) R. L. Templin and E. C. Hartmann, "Static and Repeated Load Tests of Aluminum Alloy and Steel Riveted Hull Plate Splices," *Technical Paper No. 5*, Aluminum Research Labs.

1942

(141) Anon., "Bending Fatigue Strength of Anodized Aluminum," *Light Metals*, Vol. 5, p. 223.

(142) Franz Bollenrath and Heinrich Cornelius, "The Determination of the Injury Line of an Age-Hardened Wrought Aluminum-Copper-Magnesium Alloy," *Zeitschrift für Metallkunde*, Vol. 34, p. 150.

(143) H. Cornelius, "Torsional Fatigue and 'Damage Lines' of an Age-Hardenable Aluminum-Copper-Magnesium Alloy after Various Treatments," *Metallwirtschaft*, Vol. 21, p. 363.

(144) T. J. Dolan, "Effect of Range of Stress and of Special Notches on Fatigue Properties of Aluminum Alloys Suitable for Airplane Propellers," *Technical Note No. 852*, Nat. Advisory Comm. Aeronautics.

(145) E. C. Hartmann and G. W. Stickley, "The Direct-Stress Fatigue Strength of 17S-T Aluminum Alloy Throughout the Range from ½ to 500,000,000 Cycles of Stress," *Technical Note No. 865*, Nat. Advisory Comm. Aeronautics.

(146) E. C. Hartmann and G. W. Stickley, "Summary of Results of Tests Made by Aluminum Research Laboratories of Spot-Welded Joints and Structural Elements," *Technical Note No. 869*, Nat. Advisory Comm. Aeronautics; *Journal*, Am. Welding Soc., Vol. 12, p. 233s.

(147) R. Irmann, "The Fatigue Strength of Aluminum and Its Alloys," *Schweizer Archiv für angewantde Wissenschaft und Technik*, Vol. 8, p. 52; *Chemical Abstracts*, Vol. 37, p. 4667.

(148) W. Müller, "The Determination of the Influence of Pickling and Anodic Oxidation on the Fatigue (Alternate Bending Test) of Various Aluminum Alloys," *Korrosion und Metallshutz*, Vol. 18, p. 56; *Journal*, Inst. Metals, Vol. 12, p. 5.

(149) Tasio Nisihara and Ninoru Kawamoto, "Fatigue Testing of Duralumin Under Combined Bending and Torsion," *Journal*, Inst. Metals, Vol. 8, p. 238.

(150) Erich Siebel, Wolfgang Steurer, and Gustav Stähli, "Testing of Light Metal Alloys at Elevated Temperatures Under Simultaneous Static and Dynamic Stress," *Zeitschrift für Metallkunde*, Vol. 34, p. 145.

(151) R. Sterner-Rainer and W. Jung-König, "On the Fatigue Limit in Alternate Bending Tests of Some Aluminum Alloys Under Corrosive Influences in Comparison with Cast Bronze and Red Brass," *Korrosion und Metallschutz*, Vol. 18, p. 337; *Journal*, Inst. Metals, Vol. 12, p. 113.

(152) G. W. Stickley, "The Fatigue Strengths of Some Wrought Aluminum Alloys," *Bulletin*, Nat. Advisory Comm. Aeronautics; also *Wartime Report W-83*, Nat. Advisory Comm. Aeronautics.

(153) G. W. Stickley, "Improvement of Fatigue Life of an Aluminum Alloy by Overstressing," *Technical Note No. 857*, Nat. Advisory Comm. Aeronautics.

(154) Satoru Tsuda, "X-ray Study of Fatigue of Light Alloys," *Journal*, Central Aeronautical Inst. (Japan), Vol. 1, p. 160; *Metallurgical Abstracts*, Vol. 16, p. 540 (1949).

(155) H. Unckel, "Fatigue Test on Extruded Aluminum Alloy Rods in the Longitudinal and Lateral Directions," *Metallwirtschaft*, Vol. 21, p. 427.

1943

(156) H. J. Andrews and G. W. Stickley, "Effect of Scratches on Fatigue Strength of Alclad Sheet," *Aviation*, Vol. 42, No. 6, p. 154.

(157) Reginald B. Bland and Paul E. Sandorff, "The Control of Life Expectancy in Airplane Structures," *Aeronautical Engineering Review*, Vol. 2, No. 8, p. 7.

(158) W. Buchmann, "Influence of the Cross-Sectional Area on the Fatigue Strength of Light Alloys," *Zeitschrift des Vereines deutscher Ingenieure*, Vol. 87, p. 325.

(159) Harold Crate, "A Preliminary Study of

Machine-Countersunk Flush Rivets Subjected to a Combined Static and Alternating Shear Load," *Bulletin No. 3L01*, Nat. Advisory Comm. Aeronautics; also *Wartime Report L-495*, Nat. Advisory Comm. Aeronautics.

(160) Thomas J. Dolan, "Certain Mechanical Strength Properties of Aluminum Alloys 25S-T and X76S-T," *Technical Note No. 914*, Nat. Advisory Comm. Aeronautics.

(161) E. C. Hartmann, C. F. Wescoat, and M. W. Brennecke, "Prescription for Head Cracks in 24S-T Rivets," *Aviation*, Vol. 42, p. 139.

(162) H. W. Russell, "Fatigue Strength and Related Characteristics of Spot-Welded Joints in 24S-T Alclad Sheet," *Advance Report 3L01*, Nat. Advisory Comm. Aeronautics; also *Wartime Report W-61*, Nat. Advisory Comm. Aeronautics.

(163) H. W. Russell, H. W. Gillett, L. R. Jackson, and G. M. Foley, "The Effect of Surface Finish on the Fatigue Performance of Certain Propeller Materials," *Technical Note No. 917*, Nat. Advisory Comm. Aeronautics.

(164) H. W. Russell and L. R. Jackson, "Progress Report on Fatigue of Spot-Welded Aluminum," *Advance Report*, Nat. Advisory Comm. Aeronautics; also *Wartime Report W-38*, Nat. Advisory Comm. Aeronautics.

(165) H. W. Russell, L. R. Jackson, H. J. Grover, and W. W. Beaver, "Fatigue Characteristics of Spot-Welded 24S-T Aluminum Alloy," *Advance Report 3F16*, Nat. Advisory Comm. Aeronautics; also *Wartime Report W-64*, Nat. Advisory Comm. Aeronautics.

(166) V. Seliger, "Effect of Rivet Pitch Upon the Fatigue Strength of Single-Row Riveted Joints of 0.025- to 0.025-inch 24S-T Alclad," *Technical Note No. 900*, Nat. Advisory Comm. Aeronautics.

(167) E. von Rajokovics, "Concerning the Influences on the Fatigue Strength of Aluminum Alloys," *Metallwirtschaft*, Vol. 22, p. 225.

1944

(168) Anon., "Fatigue and Impact Characteristics and Notch Effect in Tension of Artificially Aged Aluminum Alloys," *Progress Report O.S.R.D. No. 3579*, Nat. Defense Research Comm.

(169) Anon., "Mechanical Properties of Aluminum Screws," *Light Metals*, Vol. 7, p. 154.

(170) W. C. Brueggeman, M. Mayer, Jr., and W. H. Smith, "Axial Fatigue Tests at Zero Mean Stress of 24S-T Aluminum-Alloy Sheet with and without a Circular Hole," *Technical Note No. 955*, Nat. Advisory Comm. Aeronautics.

(171) W. C. Brueggeman, P. Krupen, and F. C. Roop, "Axial Fatigue Tests of 10 Airplane Wing-Beam Specimens by the Resonance Method," *Technical Note No. 959*, Nat. Advisory Comm. Aeronautics.

(172) Heinrich Cornelius, "Influence of Clamping Effect on the Fatigue Behavior of Work-Hardened Ductile Aluminum-Copper-Manganese Alloys," *Zeitschrift für Metallkunde*, Vol. 36, p. 101.

(173) E. C. Hartmann, J. O. Lyst, and H. J. Andrews, "Fatigue Tests of Riveted Joints. Progress Report of Tests of 17S-T and 53S-T Joints," *Advance Report 4115*, Nat. Advisory Comm. Aeronautics; also *Wartime Report W-55*, Nat. Advisory Comm. Aeronautics.

(174) W. F. Hess, R. A. Wyant, F. J. Winsor, and H. C. Cook, "An Investigation of the Fatigue Strength of Spot Welds in the Aluminum Alloy Alclad 24S-T," *Progress Report No. 15 on Aircraft Spotwelding Research*, Nat. Advisory Comm. Aeronautics.

(175) S. Luthander and G. Wallgren, "An Experimental Determination of the Fatigue Diagram for Tension and Compression in Alclad Sheet," *Report No. 5*, Aeronautical Research Inst. of Sweden.

(176) H. W. Russell, L. R. Jackson, H. J. Grover, and W. W. Beaver, "Fatigue Strength and Related Characteristics of Joints in 24S-T Alclad Sheet," *Advance Report 4E30*, Nat. Advisory Comm. Aeronautics; also *Wartime Report W-63*, Nat. Advisory Comm. Aeronautics.

(177) H. W. Russell, L. R. Jackson, H. J. Grover, and W. W. Beaver, "Fatigue Strength and Related Characteristics of Aircraft Joints. I—Comparison of Spot Weld and Rivet Patterns in 24S-T Alclad Sheet—Comparison of 24S-T Alclad and 75S-T Alclad," *Advance Report 4F01*, Nat. Advisory Comm. Aeronautics; also *Wartime Report W-56*, Nat. Advisory Comm. Aeronautics.

(178) P. L. Thorpe and G. Tremain, "Fatigue Properties of Duralumin, RR56 and RR59 Alloys at 100 C," *Report of Engineering Division 75/44*, Nat. Physics Lab.

(179) Satoru Tsuda, "Fatigue of Light Metals," *Journal*, Central Aeronautical Inst. (Japan), Vol. 3, p. 51; *Metallurgical Abstracts*, Vol. 16, p. 540 (1949).

1945

(180) H. J. Andrews and M. Holt, "Fatigue Tests on ⅛-inch Aluminum-Alloy Rivets," *Technical Note No. 971*, Nat. Advisory Comm. Aeronautics.

(181) Anon., "Fatigue and Static Tests of Riveted Joints in 0.032-inch Alclad 75S-T Sheet," *Laboratory Report No. 65183 (PR2)*, Nat. Bureau Standards.

(182) J. A. Bennett, "Effect of Fatigue-Stressing Short of Failure on Some Typical Aircraft Metals," *Technical Note No. 992*, Nat. Advisory Comm. Aeronautics.

(183) W. C. Brueggeman, M. Mayer, and W. H. Smith, "Axial Fatigue Tests of Two Stress Amplitudes of 0.032-inch 24S-T Sheet Specimens with a Circular Hole," *Technical Note No. 983*, Nat. Advisory Comm. Aeronautics.

(184) Daniel M. Davis, "Fatigue Failures of Aircraft Parts—Their Cause and Cure," *Automotive and Aviation Industries*, Vol. 92, p. 34; *Aeronautical Engineering Review*, Vol. 5, No. 1, p. 15 (1946).

(185) James L. Erickson, "Fatigue in Light Metals," *Light Metal Age*, Vol. 3, p. 17.

(186) F. A. Fox, "The Properties of Some Magnesium-Aluminum-Zinc Casting Alloys and the Incidence of Microporosity," *Journal*, Inst. Metals, Vol. 71, p. 415.

(187) L. R. Jackson, H. J. Grover, and R. C. McMaster, "Fatigue Properties of Aircraft Materials and Structures," *Report No. 6600*, Office of Scientific Research and Development.

(188) J. T. Lapsley, D. M. Finch, and J. E. Dorn, "Supplemental Report on Study of the Forming Properties of Aluminum Alloy Sheets—Part XVI-A—Fatigue Endurance of Flush-Riveted Panels," *Report No. W-201*, Office of Production, Research, and Development.

(189) G. A. Maney and L. T. Wyly, "Fatigue Strength of Flush-Riveted Joints for Aircraft Manufactured by Various Riveting Methods," *Advance Report 5H28*, Nat. Advisory Comm. Aeronautics; also *Wartime Report W-82*, Nat. Advisory Comm. Aeronautics.

(190) M. A. Miner, "Cumulative Damage in Fatigue," *Transactions*, Am. Soc. Mechanical Engrs., Vol. 67, p. A159; Vol. 68, p. A169.

(191) Milton A. Miner, "Experimental Verification of Cumulative Fatigue Damage," *Automotive and Aviation Industries*, Vol. 93, No. 11, p. 20.

(192) Milton A. Miner, "How Cumulative Damage Affects Life," *Machine Design*, Vol. 17, p. 111.

(193) H. F. Moore, "A Study of Size Effect and Notch Sensitivity in Fatigue Tests of Steel," *Proceedings*, Am. Soc. Testing Mats., Vol. 45, p. 507.

(194) H. F. Moore, "The Fatigue Strength of Aluminum and Magnesium Alloys," *Aluminum and Magnesium*, Vol. 2, No. 2, p. 14.

(195) R. L. Moore and H. N. Hill, "Comparative Fatigue Tests of Riveted Joints of Alclad 24S-T, Alclad 24S-T81, Alclad 24S-RT, Alclad 24S-T86, and Alclad 75S-T Sheet," *Bulletin No. 5F11*, Nat. Advisory Comm. Aeronautics; also *Wartime Report W-76*, Nat. Advisory Comm. Aeronautics.

(196) C. R. Phillips and R. W. Ridley, "The Effect on the Fatigue Resistance of Shot Blasting the Machined Surfaces of Two Cast Aluminum Alloys," British Ministry of Aircraft Production.

(197) Abbott A. Putnam, "An Analysis of Life Expectancy of Airplane Wings in Normal Cruising Flight," *Report No. 805*, Nat. Advisory Comm. Aeronautics.

(198) E. R. Schenkel, "Fatigue Failure in Shear Panels of Aluminum and Magnesium Alloys," *Product Engineering*, Vol. 16, p. 222.

(199) Victor Seliger, "A Suggested New Parameter for Fatigue Strength Analysis," ASTM BULLETIN, No. 132, p. 29.

(200) G. M. Yoder, R. C. Bowman, and J. B. Johnson, "Endurance Properties of Spot-Welded and Riveted Joints in Aluminum Alloys," *Memorandum Report No. TSEA1-4-3481, Addendum III*, AAF Eng. Div.

1946

(201) K. Arnstein, "Fatigue Failures in Aircraft," *Proceedings*, Soc. Experimental Stress Analysis, Vol. III, No. 2, p. 124.

(202) Given Brewer and Herman C. Ibsen, "Brittle Failure of Hogged-Out Fittings from 14S-T Billets," *Metal Progress*, Vol. 49, p. 566.

(203) Harold Crate, David W. Ochiltree, and Walter T. Grives, "Effect of Ratio of Rivet Pitch to Rivet Diameter on the Fatigue Strength of Riveted Joints of 24S-T Aluminum-Alloy Sheet," *Technical Note No. 1125*, Nat. Advisory Comm. Aeronautics.

(204) D. W. Drake, "The Effect of Notches on Static and Fatigue Strength," *Journal of the Aeronautical Sciences*, Vol. 13, p. 259.

(205) G. Forrest, "Some Experiments on the Effects of Residual Stresses on the Fatigue

of Aluminum Alloys," *Journal*, Inst. Metals, Vol. 72, p. 1.

(206) G. H. Found, "The Notch-Sensitivity in Fatigue of Some Magnesium-Base and Aluminum-Base Alloys," *Proceedings*, Am. Soc. Testing Mats., Vol. 46, p. 715.

(207) H. W. Gillett, H. J. Grover, and L. R. Jackson, "American Trends in Endurance Testing," *Revue de métallurgie*, Vol. 43, p. 268.

(208) W. F. Hess, R. A. Wyant, F. J. Winsor, and H. C. Cook, "An Investigation of the Fatigue Strength of Spot Welds in Aluminum-Alloy Alclad 24S-T" *Journal*, Am. Welding Soc., Vol. 25, p. 344s.

(209) M. Holt, "Fatigue Failures of Bolted, Welded and Riveted Connections," *Proceedings*, Soc. Experimental Stress Analysis, Vol. III, No. 2, p. 131.

(210) L. R. Jackson, H. J. Grover, and R. C. McMaster, "Advisory Report on Fatigue Properties of Aircraft Materials and Structures," *O.S.R.D. Report No. 6600.*

(211) L. R. Jackson, W. M. Wilson, H. F. Moore, and H. J. Grover, "The Fatigue Characteristics of Bolted Lap Joints of 24S-T Alclad Sheet Materials," *Technical Note No. 1030*, Nat. Advisory Comm. Aeronautics.

(212) H. F. Moore, "Effect of Size and Notch Sensitivity on Fatigue Characteristics of Two Metallic Materials," *AAF Technical Report No. 5726.*

(213) D. L. Moseley, "Notch Effects in High-Strength Aluminum Alloy Spar Caps," *Journal of the Aeronautical Sciences*, Vol. 13, p. 397.

(214) M. S. Paterson, "Notch Sensitivity of Metals," *The Failure of Metals by Fatigue*, Melbourne Univ. Press, p. 309.

(215) A. A. Putnam and T. O. Reisert, "An Analysis of the Fatigue Life of an Airplane Wing Structure Under Overload Conditions," *Research Bulletin L5K29(G)*, Nat. Advisory Comm. Aeronautics.

(216) H. Sutton, "Fatigue Problems Associated with Aircraft Materials," *The Failure of Metals by Fatigue,* Melbourne Univ. Press, p. 40.

1947

(217) Anon., "Flexural Fatigue Tests of Some Aluminum Alloy Wing Beams of Several Designs," *Progress Report No. 1, TED, NBS 2411*, Bur. Aeronautics.

(218) William N. Findley, "New Apparatus for Axial-Load Fatigue Testing," ASTM BULLETIN, No. 147, p. 54.

(219) F. B. Fuller and T. T. Oberg, "Fatigue Characteristics of Rotating-Beam *versus* Rectangular Cantilever Specimens of Steel and Aluminum Alloys," *Proceedings*, Am. Soc. Testing Mats., Vol. 47, p. 665.

(220) C. B. Gleason, "Influence of Shot-Peening on Fatigue Strength of 14S-T Alloy," *Iron Age*, Vol. 159, p. 62.

(221) H. J. Grover and L. R. Jackson, "Fatigue Tests on Some Spot-Welded Joints in Aluminum-Alloy Sheet Materials," *Journal*, Am. Welding Soc., Vol. 26, No. 4, p. 215s.

(222) E. C. Hartmann, Marshall Holt, and A. N. Zamboky, "Static and Fatigue Tests of Arc-Welded Aluminum Alloy 61S-T Plate," *Journal*, Am. Welding Soc., Vol. 26, No. 3, p. 129s.

(223) R. C. McMaster and H. J. Grover, "Radiography and the Fatigue Strength of Spot Welds in Aluminum Alloys," *Journal*, Am. Welding Soc., Vol. 26, No. 3, p. 223.

(224) R. C. McMaster and H. J. Grover, "Spot-Welded Aluminum Lap Joints Designed for Repeated Loads," *Product Engineering*, Vol. 18, p. 112.

(225) W. G. Pierpont, "Fatigue Tests of Major Aircraft Structural Components," *Proceedings*, Soc. Experimental Stress Analysis, Vol. IV, No. 2, p. 1.

(226) Ernst Raub, "Influence of Hard Chromium Plating on the Fatigue Strength of Aluminum Alloys," *Metallforschung*, Vol. 2, p. 121. Translated and condensed by M. G. Corson, *Metal Progress*, Vol. 59, p. 412 (1951).

(227) L. Shapiro, "Notch Effects in High Strength Aluminum Alloys," *Iron Age*, Vol. 159, p. 52.

(228) R. L. Templin and Marshall Holt, "Static and Fatigue Strengths of Welded Joints in Aluminum Manganese Alloy Sheet and Plates," *Journal*, Am. Welding Soc., Vol. 26, No. 12, p. 705s.

(229) Gunnar Wallgren, "Fatigue Tests on Multiple-Riveted Joints of 75S-T Aluminum Alloy," *Report No. HU-220*, Aeronautical Research Inst. of Sweden. (Translation N-29585 available from Nat. Advisory Comm. Aeronautics.)

1948

(230) W. C. Brueggeman and M. Mayer, Jr., "Axial Fatigue Tests at Zero Mean Stress of 24S-T and 75S-T Aluminum-Alloy Strips with A Central Circular Hole," *Technical Note No. 1611*, Nat. Advisory Comm. Aeronautics.

(231) Walter Bungardt and Eugen Osswald,

"Effect of Forging on the Fatigue Bending Strength of Several Aluminum-Copper-Magnesium Alloys with Varying Manganese Contents," *Zeitschrift für Metallkunde*, Vol. 39, p. 185; *Metals Review*, Vol. 22, p. 24 (1949).

(232) R. Cazaud, "Fatigue of Metals" (French) (book). Translated by Fenner, Chapman & Hall Ltd. London (1953).

(233) T. J. Dolan, F. E. Richart, Jr., and C. E. Work, "7th Progress Report on An Investigation of the Behavior of Materials Under Repeated Stress," Univ. of Illinois.

(234) M. G. Fontana, "Mechanical Properties and Physical Metallurgy of Aircraft Alloys at Very Low Temperatures, Part II, Strength Properties and Hardness," *AAF Report No. 5662*.

(235) R. F. Hanstock, "The Effect of Vibration on a Precipitation Hardening Aluminum Alloy," *Journal*, Inst. Metals, Vol. 74, p. 469.

(236) F. M. Howell, G. W. Stickley, and J. O. Lyst, "Effects of Surface Finish, of Certain Defects, and of Repair of Defects by Welding, on Fatigue Strength of 355-T6 Sand-Castings; and Effects of Prior Fatigue Stressing on Tensile Properties," *Technical Note No. 1464*, Nat. Advisory Comm. Aeronautics.

(237) L. R. Jackson, H. C. Cross, and J. M. Berry, "Tensile, Fatigue, and Creep Properties of Forged Aluminum Alloys at Temperatures Up to 800 F," *Technical Note No. 1469*, Nat. Advisory Comm. Aeronautics.

(238) L. R. Jackson, H. J. Grover, and D. O. Lesser, "Fatigue Strength and Related Characteristics of Aircraft Materials," *Report No. G-623*, Battelle Memorial Inst.

(239) S. I. Liu, J. J. Lynch, E. J. Ripling, and G. Sachs, "Low Cycle Fatigue of the Aluminum Alloy 24S-T in Direct Stress," *Transactions*, Am. Inst. Mining and Metallurgical Engrs., Vol. 175, p. 469.

(240) S. Luthander and G. Wallgren, "An Experimental Determination of the Fatigue Diagram for Tension and Compression in Alclad Sheet," *Report No. 5* (*Translation No. 8*), Royal Swedish Air Board (Stockholm).

(241) H. F. Moore, "The Effect of Size and Notch Sensitivity on Fatigue Characteristics of Two Metallic Materials," *Air Force Technical Report No. 5726, Part I.*

(242) B. W. Mott and J. Thompson, "Investigations on Aluminum Alloys of High Strength at Room Temperature," *Metal Treatment and Drop Forging*, Vol. 15, p. 91.

(243) T. T. Oberg and R. J. Rooney, "Static and Fatigue Tests of Cast and Forged I-Beams of Aluminum and Magnesium Alloys," *AAF Technical Report No. 5701.*

(244) R. J. Rooney, "Fatigue Tests on Flash Welded 75S Alloy," *Air Materiel Command Report, Series MCREXB-590-7-1.*

(245) H. W. Russell, L. R. Jackson, H. J. Grover, and W. W. Beaver, "Fatigue Strength and Related Characteristics of Aircraft Joints. II—Fatigue Characteristics of Sheet and Riveted Joints of 0.040-inch 24S-T, 75S-T, and R303-T275 Aluminum Alloys," *Technical Note No. 1485*, Nat. Advisory Comm. Aeronautics.

(246) J. A. Sauer, "A Study of Fatigue Phenomena Under Combined Stress," *Proceedings*, Seventh International Congress for Applied Mechanics, Vol. 4, p. 150.

(247) Hugo Vosskuhler, "A Contribution to the Problem of Determining the Fatigue Strength of Light-Metal Alloys," *Zeitschrift für Metallkunde*, Vol. 39, p. 79.

(248) G. Wallgren, "An Experimental Determination of the Fatigue Diagram for Alclad Sheet Specimens with Rivet Holes, Subjected to Tension and Compression," *Royal Swedish Air Board Report, Translation No. 9; Applied Mechanics Reviews*, Vol. 3, No. 5, p. 144 (1950).

(249) Georges Welter, "Fatigue Tests of Spot Welds: Improvement of Their Endurance Limit by Hydrostatic Pressure," *Journal*, Am. Welding Soc., Vol. XIII, No. 6, p. 285s.

1949

(250) George W. Adams, "Tubing, Aluminum Alloy 61S-T6, Hydraulic," *Memorandum Report MCREXA-45230-220*, Engineering Division, Air Materiel Command, Wright-Patterson Air Force Base.

(251) "Manual on Fatigue Testing," Am. Soc. Testing Mats. (Issued as separate publication, *ASTM STP No. 91.*)

(252) Raymond Boccon-Gibod, "Fatigue Strength of Light Metals." *Revue de l'aluminium*, Vol. 26, p. 278; *Light Metals Bulletin*, Vol. 11, p. 1184.

(253) T. J. Dolan, F. E. Richart, Jr., and C. E. Work, "The Influence of Fluctuations in Stress Amplitude on the Fatigue of Metals," *Proceedings*, Am. Soc. Testing Mats., Vol. 49, p. 646.

(254) W. A. P. Fisher, "A Comparison of the

Endurance of Various Aircraft Structures Under Fluctuating Loading," *Report No: Structures 45* (British), Royal Aeronautical Establishment.

(255) M. G. Fontana, "Investigation of Mechanical Properties and Physical Metallurgy of Aircraft Alloys at Very Low Temperatures," *AAF Technical Report No. 5662.*

(256) O. Graf, "The Strength of Welded Aluminum Alloy Sheets in Tensile Tests and Alternating-Stress Testing," *Schweissen und Schneiden,* Vol. 1, No. 11, p. 183; *Metallurgical Abstracts,* Vol. 19, p. 887 (1952).

(257) E. C. Hartmann, F. M. Howell, and R. L. Templin, "How to Use High-Strength Aluminum Alloys," *Aviation Week,* Vol. 51, No. 15, p. 21.

(258) Marshall Holt and J. W. Clark, "A Study of End Connections for Struts," *Proceedings,* Am. Soc. Civil Engrs., Vol. 75, No. 10, p. 1477; also *Transactions,* Am. Soc. Civil Engrs., Vol. 116, p. 223 (1951).

(259) Bo K. O. Lundberg and Gunnar G. E. Wallgren, "A Study of Some Factors Affecting the Fatigue Life of Aircraft Parts with Application to Structural Elements of 24S-T and 75S-T Aluminum Alloys," *Report No. 30,* Aeronautical Research Inst. of Sweden.

(260) S. Luthander and G. Wallgren, "Determination of Fatigue Life with Stress Cycles of Varying Amplitude," *Report No. 18* (*Translation No. 10*), Aeronautical Research Inst. of Sweden.

(261) Joseph Marin, "Stress-Strain Relations in the Plastic Range for Biaxial Stresses," *Journal,* Franklin Inst., Vol. 248, p. 231.

(262) Joseph Marin, "Biaxial Tension-Tension Fatigue Strengths of Metals," *Journal of Applied Mechanics,* Vol. 16, p. 383.

(263) J. Marin and W. Shelson, "Biaxial Fatigue Strength of 24S-T Aluminum Alloy," *Technical Note No. 1889,* Nat. Advisory Comm. Aeronautics.

(264) H. F. Moore, "Report of Subcommittee on Research—Appendix to Committee E-9 Report," *Proceedings,* Am. Soc. Testing Mats., Vol. 49, p. 523.

(265) T. T. Oberg and R. J. Rooney, "Fatigue Characteristics of Aluminum Alloy 75S-T6 Plate in Reversed Bending as Affected by Type of Machine and Specimen," *Proceedings,* Am. Soc. Testing Mats., Vol. 49, p. 804.

(266) Ture T. Oberg and Robert J. Rooney, "Reversed Bending Fatigue Characteristics of Steel and High Strength Aluminum Alloys as Affected by Type of Specimen. Part I—Extruded Aluminum Alloys and Rolled 4130 Steel Plate. Part II—Aluminum Alloy 75S-T6 Plate," *AAF Technical Report No. 5775.*

(267) T. E. Pardue, J. L. Melchor, and W. B. Good, "Energy Losses and Fracture of Some Metals Resulting from a Small Number of Cycles of Strain," *Proceedings,* Soc. Experimental Stress Analysis, Vol. 7, No. 2, p. 27.

(268) D. Rosenthal, G. Sines, and G. Zizicas, "Effect of Residual Compression on Fatigue," *Welding Journal,* Vol. 28, p. 98s.

(269) J. A. Sauer, "Effect of Steady Stress on Fatigue Behavior of Aluminum," *Automotive Industries,* Vol. 101, p. 70.

(270) Alfred Schall, "X-ray Investigations of the Behavior of Materials Under Alternating Stresses," *Zeitschrift für Metallkunde,* Vol. 40, p. 417.

(271) W. P. Wallace and J. P. Frankel, "Relief of Residual Stress by a Single Fatigue Cycle," *Welding Journal,* Vol. 28, p. 565s.

(272) Gunnar Wallgren, "Fatigue Tests with Stress Cycles of Varying Amplitude," *Report No. 28,* Aeronautical Research Inst. of Sweden.

(273) C. S. Yen and T. J. Dolan, "An Experimental Study of the Effect of Thermal Activation on the Fatigue Life of 75S-T Aluminum Alloy," *Twelfth Progress Report, Investigation of the Behavior of Materials Under Repeated Stress,* Univ. of Illinois.

(274) J. L. Zambrow and M. G. Fontana, "Mechanical Properties, Including Fatigue, of Aircraft Alloys at Very Low Temperatures," *Transactions,* Am. Soc. Metals, Vol. XLI, p. 480.

1950

(275) Anon., "Alcoa Aluminum and Its Alloys," Aluminum Company of America.

(276) Anon., "Fatigue Tests on Simple Lap Welds of 24S-T Alclad Bonded with Redux and One Series of Riveted Specimens of 24S-T Alclad and 24S Rivets," *Report No. M1627,* Nat. Luchtvaartlaboratorium (Amsterdam); *Applied Mechanics Reviews,* Vol. 4, p. 355 (1951).

(277) Anon., "New Hard Coating Gains Wear Applications for Aluminum," *Materials & Methods,* Vol. 32, No. 2, p. 62.

(278) J. A. Bennett and J. L. Baker, "Effect of Prior Static and Dynamic Stresses on the Fatigue Strength of Aluminum Alloys,"

Journal of Research, Nat. Bureau Standards, Vol. 45, No. 6, p. 449; *Aviation Week*, Vol. 511, No. 15, p. 28 (1951).

(279) Franz Bollenrath, Walter Bungardt, and Hanns Gröber, "Effect of Heat Treating on the Strength of Propellers Made of Al-Zn-Mg Alloys," *Zeitschrift für Metallkunde*, Vol. 42, p. 463.

(280) Paul W. Boone, "Caustic Etching Detects Fatigue Damage," *Iron Age*, Vol. 165, p. 99.

(281) P. Brenner, "Effect of Overheating on the Fatigue-Bending Strength of Aluminum-Copper-Magnesium Alloys," *Metall*, Vol. 4, p. 502.

(282) R. J. Durham, "Fatigue Curves for Some Wrought Aluminum Alloys," *S & T Memoranda No. 8/50*, Ministry of Supply (British).

(283) Otto Graf, "Investigation of the Strength of Welded Aluminum Alloy Sheet by Means of Tensile and Fatigue Testing," *Battelle Library Review*, No. 2, p. 7.

(284) H. J. Grover, "Fatigue Notch-Sensitivities of Some Aircraft Materials," *Proceedings*, Am. Soc. Testing Mats., Vol. 50, p. 717.

(285) A. K. Head, "Statistical Properties of Fatigue Data on 24S-T Aluminum Alloy," ASTM BULLETIN, No. 169, p. 51.

(286) R. C. Henshaw, "Fatigue of Aircraft Engine Mounting Components," *Automotive Industries*, Vol. 102, p. 52.

(287) M. Holt, "Results of Shear Fatigue Tests of Joints with $\frac{3}{16}$-inch-Diameter 24S-T31 Rivets in 0.064-inch-Thick Alclad Sheet," *Technical Note No. 2012*, Nat. Advisory Comm. Aeronautics.

(288) D. M. Howard and F. C. Smith, "Fatigue and Static Tests of Flush-Riveted Joints," *Laboratory Report No. 6.4-183*, *Project No. 3517*, *Bu-AER TED NBS 2412*, Nat. Bureau Standards.

(289) J. H. James, "Electroplated Coatings on Aluminum Alloys," *Report No. AML NAM AE 411030—Part II*, Naval Air Material Center, U. S. Naval Base Station.

(290) W. W. Johnstone, C. A. Patching, and W. O. Payne, "An Experimental Determination of the Fatigue Strength of CA-12 'Boomerang' Wings." *Report No. SM 160*, Aeronautical Research Labs., Dept. of Supply (Australia).

(291) B. J. Lazan, *et al.*, "Fatigue Properties of Structural Aluminum Alloys," *Progress Report No. 1; Progress Report No. 2;* and *Final Report*, Inst. Industrial Research, Dept. of Materials Engineering, Syracuse Univ.

(292) Bo K. O. Lundberg and Gunnar G. E. Wallgren, "A Study of Some Factors Affecting the Fatigue Life of Aircraft Parts with Application to Structural Elements of 24S-T and 75S-T Aluminum Alloys," *Report No. 30*, Aeronautical Research Inst. of Sweden.

(293) J. Y. Mann, "The Effect of Surface Finish on the Fatigue Resistance of 24S-T Aluminum Alloy," *Report No. SM-147*, Aeronautical Research Labs., Dept. of Supply (Australia).

(294) J. Y. Mann and R. P. McMurrick, "New Ideas in Mechanical Testing. (2) A Note on High-Speed Fatigue Testing," *Australasian Engineer*, p. 49.

(295) J. McKeown, D. E. Dineen, and L. H. Back, "Fatigue Properties of Four Cast Aluminum Alloys at Elevated Temperatures," *Metallurgia*, Vol. 41, p. 393.

(296) K. Minamiozi and H. Okubo, "A Note on the Notch Effect of Metals," *Journal*, Franklin Inst., Vol. 249, p. 49.

(297) Toshio Nishihara and Toshiro Yamada, "The Fatigue Strength of Metallic Materials Under Alternating Stresses of Varying Amplitude" (Japanese), *Light Metals Review*, Vol. 1, p. 1.

(298) R. E. Peterson, "Discussions of a Century Ago Concerning the Nature of Fatigue, and Review of Some of the Subsequent Researches Concerning the Mechanism of Fatigue," ASTM BULLETIN, No. 165, p. 50.

(299) T. E. Piper, K. F. Finley, and A. P. Binsacca, "Fatigue Characteristics of Aircraft Materials and Fastenings," ASTM BULLETIN, No. 166, p. 60.

(300) C. N. S. Pringle and M. S. Binning, "Fatigue of Specimens from 'Z' Section DTD 364 Extrusions," *Report No: Structures 88*, Royal Aircraft Establishment (British).

(301) D. Rosenthal and George Sines, "Residual Stress and Fatigue Strength," *Metal Progress*, Vol. 58, p. 76.

(302) J. A. Sauer and D. C. Lemmon, "Effect of Steady Stress on Fatigue Behavior of Aluminum," *Transactions*, Am. Soc. Metals, Vol. 42, p. 559.

(303) F. C. Smith, W. C. Brueggeman, and R. C. Harwell, "Comparison of Fatigue Strengths of Bare and Alclad 24S-T3 Aluminum-Alloy Sheet Specimens Tested at 12 and 1000 Cycles per Minute," *Technical Note No. 2231*, Nat. Advisory Comm. Aeronautics.

(304) D. G. Sopwith, "The Resistance of Aluminum and Beryllium Bronze to Fatigue and Corrosion-Fatigue," *Report and Memorandum No. 2486*, Aeronautical Research Council (British).

(305) W. Spath, "Evaluation of Fatigue-Test Data on Materials Testing," *Metall*, Vol. 4, p. 374.

(306) G W. Stickley and F. M. Howell, "Effects of Anodic Coatings on the Fatigue Strength of Aluminum Alloys," *Proceedings*, Am. Soc. Testing Mats., Vol. 50, p. 735.

(307) W. J. Taylor and N J. F. Gunn, "The Effect of Notches on the Fatigue Strength of Three Light Alloys," *Report No: Met. 42*, Royal Aircraft Establishment (British).

(308) R. L. Templin, F. M. Howell, and E. C Hartmann, "Effect of Grain Direction on the Fatigue Properties of Aluminum Alloys," *Product Engineering*, Vol. 21, p. 126.

(309) P. S. Thorpe, G. R. Tremain, and R. W. Ridley, "The Mechanical Properties of Some Wrought and Cast Aluminum Alloys at Elevated Temperatures," *Journal*, Inst. Metals, Vol. 7, p. 111.

(310) Robert Stanton Turner, "The Effect of Rapid Changes in Temperature Upon the Fatigue Strength of a Light Alloy Used in Aircraft Construction," Thesis, Rensselaer Polytechnic Inst. (June 5).

(311) H. A. Unckel and H. H. Nyander, "The Effect of Homogenising on the Fatigue Properties of an Extruded Al-Cu-Mg Alloy," *Metallurgia*, Vol. 41, p. 155.

(312) P. B. Walker, "Fatigue of Aircraft Structures," *Report No: Structures 79*, Royal Aircraft Establishment (British).

(313) R. Weck, "The Application of the Resonance Vibration Method to the Fatigue Testing of Spot Welded Light Alloy Structures," *Welding Research* (British), Vol. 4, p. 33r.

(314) Karl Wellinger, Ernst Keil, and Gustav Stähli, "The Temperature Dependence of Fatigue Strength and the Creep-Stress Resistance of Different Light-Metal Sintered and Cast Alloys," *Zeitschrift für Metallkunde*, Vol. 41, p. 309.

(315) Georges Welter, "Stresses Around a Spot Weld Under Static and Cyclic Loads," *Welding Journal*, Vol. 29, p. 565s.

(316) D. Williams, "Strength of Aeroplanes in Relation to Repeated Loads," *Aeronautical Quarterly*, Vol. 1, No. 4, p. 291.

1951

(317) Anon., "Strength of Metal Aircraft Elements," *ANC-5*, Subcommittee on Air Force-Navy-Civil Aircraft Design Criteria, Munitions Board Aircraft Comm.

(318) Anon., "Prestress May Up Aluminum Life," *Aviation Week*, Vol. 54, No. 15, p. 28.

(319) Anon., "Fatigue in Metals," *Metal Industries*, Vol. 79, p. 322.

(320) Anon., "Prestressing Increases Aluminum Fatigue Life," *Iron Age*, Vol. 167, p. 79.

(321) W. R. Apblett and W. S. Pellini, "Performance of High-Strength Aluminum Alloy Weldments," *Welding Journal*, Vol. 30, p. 473s.

(322) M. S. Binning and J. T. Ballett, "Fatigue Tests on Specimens from 'Z' Section Extrusions," *Technical Note No: Met. 138*, Royal Aeronautical Establishment (British).

(323) R. Boccon-Gibod, "Fatigue in Light Alloy Assemblies," *Revue de métallurgie*, Vol. 48, p. 367.

(324) Thomas J. Dolan, "Electrically Excited Resonant-Type Fatigue Testing Equipment," ASTM BULLETIN, No. 175, p. 60.

(325) I. D. Eaton and Marshall Holt, "Flexural Fatigue Strength of Riveted Box Beams—Alclad 14S-T6, Alclad 75S-T6, and Various Tempers of Alclad 24S," *Technical Note No. 2452*, Nat. Advisory Comm. Aeronautics.

(326) Dwight O. Fearnow, "Investigation of the Fatigue Strength of Full-Scale Airplane Wing Structures," *Research Memo L51D13a*, Nat. Advisory Comm. Aeronautics.

(327) W. N. Findley, "Combined-Stress Fatigue Strength of 75S-T61 Aluminum Alloy with Superimposed Mean Stresses and Corrections for Yielding," Report to the Nat. Advisory Comm. Aeronautics (July).

(328) P. J. E. Forsyth, "The Process of Deformation and Workhardening Under Fatigue Stresses," *Report No: Met. 66*, Royal Aircraft Establishment (British).

(329) P. J. E. Forsyth, "Microstructural Evidence of Fatigue in Metals," *Journal*, Inst. Metals, Vol. 80, p. 181.

(330) A. M. Freudenthal, "Fatigue Testing and Test Interpretation," *Technical Report No. 26 on The Behavior of Materials Under Repeated Stress*, Univ. of Illinois.

(331) A. M. Freudenthal, "Planning and Interpretation of Fatigue Tests," Symposium on Statistical Aspects of Fatigue, Am.

Soc. Testing Mats., p. 3. (Issued as separate publication *ASTM STP No. 121.*)

(332) H. Giddings, "Aircraft Riveting," *Sheet Metal Industries*, Vol. 28, p. 833.

(333) H. J. Grover, S. M. Bishop, and L. R. Jackson, "Fatigue Strengths of Aircraft Materials; Axial-Load Fatigue Tests on Unnotched Sheet Specimens of 24S-T3 and 75S-T6 Aluminum Alloys and of SAE 4130 Steel," *Technical Note No. 2324*, Nat. Advisory Comm. Aeronautics.

(334) H. J. Grover, S. M. Bishop, and L. R. Jackson, "Fatigue Strengths of Aircraft Materials; Axial-Load Fatigue Tests of Notched Sheet Specimens of 24S-T3 and 75S-T6 Aluminum Alloys and of SAE 4130 Steel with Stress Concentration Factors of 2.0 and 4.0," *Technical Note No. 2389*, Nat. Advisory Comm. Aeronautics.

(335) H. J. Grover, S. M. Bishop and L. R. Jackson, "Fatigue Strengths of Aircraft Materials; Axial-Load Fatigue Tests on Notched Sheet Specimens of 24S-T3 and 75S-T6 Aluminum Alloys and of SAE 4130 Steel with Stress Concentration Factor of 5.0," *Technical Note No. 2390*, Nat. Advisory Comm. Aeronautics.

(336) E. C. Hartmann, Marshall Holt, and I. D. Eaton, "Static and Fatigue Strengths of High-Strength Aluminum-Alloy Bolted Joints," *Technical Note No. 2276*, Nat. Advisory Comm. Aeronautics.

(337) Marshall Holt and I. D. Eaton, "Effects of Design Details on the Fatigue Strength of 355-T6 Sand-Cast Aluminum Alloys," *Technical Note No. 2394*, Nat. Advisory Comm. Aeronautics

(338) D. M. Howard, "Flexural Fatigue Tests of Wing Beams for Bureau of Aeronautics," *Report No. 1350*, Project 0604-22-3517, Nat. Bureau Standards.

(339) R. Jacquesson and P. Laurent, "Fatigue Strength of Cold Worked Aluminum," *Metal Progress*, Vol. 59, p. 422.

(340) J. B. Johnson and D. A. Shinn, "Effect of Low Temperatures on Aircraft Metals," *Product Engineering*, Vol. 22, No. 10, p. 187.

(341) Hiroshi Kihara, "Fatigue Strength of Spot-Welded Light Alloy Joints," *Welding Journal*, Vol. 30, p. 529s.

(342) Paul-Henri Laurent, "Particular Aspects of Gliding Produced by Alternating Stresses in Annealed Aluminum" (French), *Revew de mêtallurgie*, Vol. 48, No. 6, p. 441.

(343) S. I. Liu, "Effects of Precompression on the Behavior of the Aluminum Alloy 24S-T4 During Cyclic Direct Stressing," *Transactions*, Am. Inst. Mining and Metallurgical Engrs., Vol. 191, p. 452.

(344) J. Y. Mann, "The Effect of Re-Heat Treatment and Overheating on the Fatigue Properties of 24S Aluminum Alloy," *Report No. SM-185*, Aeronautical Research Labs., Dept. of Supply (Australia).

(345) J. Y. Mann, "Some Fatigue Tests on Milled 75S Aluminum Alloy Sheet," *Structures and Materials Note 194*, Aeronautical Research Labs. (Australia).

(346) N. M. Newmark, R. J. Mosborg, W. H. Munse, and R. E. Elling, "Fatigue Tests in Axial Compression," *Proceedings*, Am. Soc. Testing Mats., Vol. 51, p. 792.

(347) T. T. Oberg and W. J. Trapp, "High-Stress Fatigue of Aluminum and Magnesium Alloys," *Product Engineering*, Vol. 22, p. 159.

(348) T. T. Oberg and E. J. Ward, "Fatigue of Tungsten Arc Butt-Welded Wrought Aluminum Alloys," *AAF Technical Report No. 6513*, Wright Air Development Center.

(349) C. A. Patching, "Interim Note on Repeated-Load Testing of 'Mustang' P-51D Wings," *SM Note No. 189*, Aeronautical Research Labs., Dept. of Supply (British).

(350) C. Petersen, "Phenomena Occurring in Continuously and Alternatingly Stressed Metal Structures: III. The Size of Notched and Unnotched Bars as a Factor in Fatigue Stress Reduction," *Zeitschrift für Metallkunde*, Vol. 42, p. 161.

(351) C. E. Phillips and A. J. Fenner, "Some Fatigue Tests on Aluminum Alloy and Mild Steel Sheet with and Without Drilled Holes," *Proceedings*, Inst. Mechanical Engrs. (London), Vol. 165, p. 125.

(352) C. E. Phillips and R. C. A. Thurston, "A Note on a Rotating Bending-Fatigue Machine for Tests at 200 C," *Technical Report No. 2674 (8592), N13047*, Aeronautical Research Council.

(353) Marcel Prot, "Results of Fatigue Tests Under Increasingly Heavy Loads," *Revue de métallurgie*, Vol. 48, p. 822.

(354) Fred M. Reinhart, W. F. Hess, R. A. Wyant, F. J. Winsor, and R. R. Nash, "Mechanical and Corrosion Tests of Spot-Welded Aluminum Alloys," *Technical Note No. 2538*, Nat. Advisory Comm. Aeronautics.

(355) M. Ros, "Fatigue Strength of Metals: Notched Parts," *Metallurgia italiana*, Vol. 43, p. 512.

(356) M. Ros, "The Fatigue of Metals: Grooved Parts," *Revue de métallurgie*, Vol. 48, p. 723.

(357) D. Rosenthal and G. Sines, "Effect of Residual Stress on the Fatigue Strength of Notched Specimens," *Proceedings*, Am. Soc. Testing Mats., Vol. 51, p. 593.

(358) Alfred Schaal, "The Influence of Size on Yield Point and Bending Fatigue Resistance," *Zeitschrift für Metallkunde*, Vol. 42, p. 279.

(359) Frank C. Smith, D. M. Howard, Ira Smith, and Richard Harwell, "A Fatigue Testing Machine for Applying a Sequence of Loads of Two Amplitudes," *Technical Note No. 2327*, Nat. Advisory Comm. Aeronautics.

(360) J. W. Spretnak, M. G. Fontana, and H. E. Brooks, "Notched and Unnotched Tensile and Fatigue Properties of Ten Engineering Alloys at 25 C and −196 C," *Transactions*, Am. Soc. Metals, Vol. 43, p. 547.

(361) H. Vosskuhler, "Fatigue Strength of Wrought Aluminum Alloys," *Metall*, Vol. 5, No. 7/8, p. 135.

(362) H. Weigand, "Relationship of Cross-Sectional Area and Fatigue Strength for Different Materials," *Zeitschrift für Vereines deutscher Ingenieure*, Vol. 93, No. 99, p. 89.

(363) Georges Welter, "Stress Distribution and Fatigue Resistance of Alclad 24S-T Multiple Spot Welds," *Report No. 308*, Laboratoire de Recherches et D'Essais des Matireaueff, Ecole Polytechnique (Montreal).

(364) J. Wood, "Investigation of Cast Secondary Aluminum Alloys; Fatigue Tests," *Metal Industry*, Vol. 78, p. 458.

(365) C. A. Zapffe and C. O. Worden, "Fractographic Registrations of Fatigue," *Transactions*, Am. Soc. Metals, Vol. 43, p. 958.

1952

(366) Anon., "Aeronautical Research in Australia," *Engineering*, Vol. 173, p. 309.

(367) Anon., "The Fatigue Properties of Unmachined and Machined Extruded Sections, by the Aluminum Laboratories Limited," *S & T Memorandum No. 7/52*, Ministry of Supply (British).

(368) V. I. Arkharov and A. K. Semenova, "Thermal Fatigue of Aluminum Single Crystals," *Doklady Akademii Nauk SSSR*, (New Series), Vol. 83, p. 681.

(369) Hermann Bürnheim, "Recent Realizations on the Endurance of Aluminum Sheet Joints by Riveting," *Aluminium*, Vol. 28, p. 140.

(370) Charles B. Cliett, "Flexural Fatigue Strength of Anodized 24S-T Aluminum-Alloy Sheet," *Aeronautical Engineering Review*, Vol. 11, p. 29.

(371) W. J. Craig, "An Electron Microscope Study of the Development of Fatigue Failures," *Proceedings*, Am. Soc. Testing Mats., Vol. 52, p. 877.

(372) T. J. Dolan and Herbert F. Brown, "Effect of Prior Repeated Stressing on the Fatigue Life of 75S-T Aluminum," *Proceedings*, Am. Soc. Testing Mats., Vol. 52, p. 733.

(373) W. N. Findley, "Fatigue of 76S-T61 Aluminum Alloy Under Combined Bending and Torsion," *Proceedings*, Am. Soc. Testing Mats., Vol. 52, p. 818.

(374) W. N. Findley, B. A. Century, and C. P. Hendrickson, "Fatigue Tests Under Axial Loads of Aluminum Joints Bonded with a Resinous Adhesive," ASTM BULLETIN, No. 179, p. 67.

(375) W. A. P. Fisher, "Fatigue of Helicopters," *Aircraft Engineering*, Vol. 24, No. 278, p. 106; No. 286, p. 376.

(376) W. A. P. Fisher, R. H. Cross, and G. M. Norris, "Pretensioning for Preventing Fatigue Failure in Bolts; Simple Theory and an Account of Experiments Carried Out at the R.A.E.," *Aircraft Engineering*, Vol. 24, No. 208, p. 160.

(377) W. A. P. Fisher and W. J. Winkworth, "Improvements in the Fatigue Strength of Joints by the Use of Interference Fits," *Report No: Structures 127*, Royal Aircraft Establishment (British).

(378) P. G. Forrest and H. J. Tapsell, "Correlation of Fatigue Strength in Bending and Direct Stress," *Engineering*, Vol. 173, No. 4507, p. 757.

(379) P. J. E. Forsyth, "Some Further Observations on the Fatigue Process in Pure Aluminum," *Report No: Met. 70*, Royal Aircraft Establishment (British).

(380) H. J. Grover, W. S. Hyler, and L. R. Jackson, "Fatigue Strengths of Aircraft Materials. Axial-Load Fatigue Tests on Notched Sheet Specimens of 24S-T3 and 75S-T6 Aluminum Alloys and of SAE 4130 Steel with Stress-Concentration Factor of 1.5," *Technical Note No. 2639*, Nat. Advisory Comm. Aeronautics.

(381) N. J. F. Gunn, "Fatigue Properties at Low Temperature on Transverse and Longitudinal Notched Specimens of DTD 373A Aluminum Alloy," *Technical Note*

No: Met. 163, Royal Aircraft Establishment (British).

(382) H. H. Hanink, "Application of Titanium to Aircraft Engines," *Journal,* Soc. Automotive Engrs., Vol. 60, No. 8, p. 25.

(383) H. H. Hanink, "Titanium in Aircraft Engine Parts, An Analysis," *Iron Age,* Vol. 169, No. 20, p. 121.

(384) H. F. Hardrath and E. C. Utley, "An Experimental Investigation of the Behavior of the 24S-T4 Aluminum Alloy Subjected to Repeated Stresses of Constant and Varying Amplitudes," *Technical Note No. 2798,* Nat. Advisory Comm. Aeronautics.

(385) A. Hartman, "Investigation of Notch Sensitivity of 24S-T and 75S-T Alclad Under Pulsating Tensile Load," *Report M.1819,* Nat. Luchtvaartlaboratorium (Amsterdam).

(386) A. Hartman and G. C. Duyn, "A Comparative Investigation on the Fatigue Strength at Fluctuating Tension of Several Types of Riveted Lap Joints, a Series of Bolted and Some Series of Glued Lap Joints of 24S-T Alclad," *Report No. M.1857,* Nat. Luchtvaartlaboratorium (Amsterdam).

(387) H. J. Hilgendorff, "Aluminum as a Material for Cable Armor," *Aluminium,* Vol. 28, p. 144.

(388) Marshall Holt and E. C. Hartmann, "Fatigue Tests on Aluminum Alloy Spot-Welded Joints," *Welding Journal,* Vol. 31, p. 183s.

(389) F. H. Hooke, "Preliminary Note on the Fatigue Life of an Aeroplane Constructed of High-Strength Aluminum Alloy Under Australian Operating Conditions," *Structures and Materials Technical Memorandum No. 28,* Aeronautical Research Labs., Dept. of Supply (Melbourne).

(390) Darnley M. Howard and Frank C. Smith, "Fatigue and Static Tests of Flush-Riveted Joints," *Technical Note No. 2709,* Nat. Advisory Comm. Aeronautics.

(391) R. Irmann, "Forging Aluminum-Base Materials and Their Fatigue Strength at Elevated Temperature," *Metall,* Vol. 6, p. 608.

(392) R. Irmann, "Sintered Aluminum with High Strength at Elevated Temperatures," *Metallurgia,* Vol. 46, No. 275, p. 125.

(393) G. R. Irwin and J. A. Kies, "Fracturing and Fracture Dynamics," *Welding Journal,* Vol. 31, p. 95s.

(394) Paul Laurent, "Studies of Structural Deformations Produced in Metals by Alternating Stresses" (book), Service de Documentation et d'Information Technique de l'Aeronautique (Paris, France); *Publications scientifiques et techniques du ministère de l'air,* No. 256, p. 116; *Chemical Abstracts,* Vol. 46, p. 7502.

(395) B. J. Lazan and A. A. Blatherwick, "Fatigue Properties of Aluminum Alloys at Various Direct Stress Ratios," *Technical Report No. 52-307, Parts I & II,* Wright Air Development Center.

(396) Luigi Locati, "Fatigue-Test Programming. Variable-Amplitude Rotating Bend Tests," *Metallurgia italiana,* Vol. 44, p. 135.

(397) J. P. Lyle, Jr., "Excellent Products of Aluminum Powder Metallurgy," *Metal Progress,* Vol. 62, No. 6, p. 109.

(398) C. W. MacGregor and N. Grossman, "Effects of Cyclic Loading on Mechanical Behavior of 24S-T4 and 75S-T6 Aluminum Alloys and SAE 4130 Steel," *Technical Note No. 2812,* Nat. Advisory Comm. Aeronautics.

(399) J. Y. Mann, "The Effect of Rate of Cycling on the Fatigue Properties of 24S-T Aluminum Alloy," *Report No. SM188,* Aeronautical Research Lab., Dept. of Supply (Australia).

(400) S. M. Marco, W. L. Starkey, and T. G. Foster, "Fatigue Characteristics of 76S-T61 Aluminum Alloy and 4340 Steel, Final Report," *Report No. 416,* Ohio State Univ. Research Foundation.

(401) Joseph Marin and W. P. Hughes, "Fatigue Strengths of 14S-T4 Aluminum Alloy Subjected to Biaxial Tensile Stresses," *Technical Note No. 2704,* Nat. Advisory Comm. Aeronautics.

(402) R. H. Meyers, "Repeated-Load Tests of Model F8F Airplane Wings," *Report No. ASL NAM DE-281,* Aeronautical Structures Lab., Naval Air Material Center, Philadelphia, Pa.

(403) J. B. B. Owen, "Service Failures in Aircraft Structures Associated with Fatigue. Repeated or Dynamic Loads," *R. & M. 2668 (9426),* Aeronautical Research Council (British).

(404) M. H. Polzin, "A Researcher's Casebook on Magnesium Truck Wheels," *Journal,* Soc. Automotive Engrs., Vol. 60, No. 8, p. 61.

(405) K. D. Raithby, "Fatigue Tests on Typical Two-Spar Light-Alloy Structures (Meteor 4 Tailplanes) Under Reverse Loading," *Technical Report C.P. 88*, Aeronautical Research Council (British).

(406) K. D. Raithby, "Variation in Strength of Nominally Identical Tailplanes, A Report on Research Revealing the Extent of Scatter in the Strength of Light Alloy Structures Manufactured to the Same Design," *Aircraft Engineering*, Vol. 24, No. 282.

(407) J. W. Riches, O. D. Sherby, and J. E. Dorn, "The Fatigue Properties of Some Binary Alpha Solid Solutions of Aluminum," *Transactions*, Am. Soc. Metals, Vol. 44, p. 882.

(408) J. H. Rondeel, R. Kruithof, and F. J. Plantema, "Comparative Fatigue Tests with 24S-T Alclad Riveted and Bonded Stiffened Panels," *Report S.416*, Nat. Luchtvaartlaboratorium (Amsterdam); *Metals Review*, Vol. 27 (1954).

(409) Joseph L. Rosenholtz and Dudley T. Smith, "Dilastrain Method for Determining Endurance Limit of Materials," *Metal Progress*, Vol. 61, No. 2, p. 85.

(410) R. J. Schliekelmann, Jr., "Bonded Joints in the Construction of Metal Aircraft," Aeronautical Technical Section of the Royal Dutch Aeronautical Soc., January 9.

(411) G. M. Sinclair, "An Investigation of the Coaxing Effect in Fatigue of Metals," *Proceedings*, Am. Soc. Testing Mats., Vol. 52, p. 743.

(412) G. W. Stickley and K. O. Bogardus, "Effects of Machining Specimens on the Results of Tension Tests of Annealed Aluminum Alloys," *Proceedings*, Am. Soc. Testing Mats., Vol. 52, p. 1079.

(413) P. Litherland Teed, "Fatigue of Aircraft Materials with Special Reference to Microstructure," *Journal*, Royal Aeronautical Soc., Vol. 56, p. 427.

(414) P. Litherland Teed, "The Influence of Metallographic Structure on Fatigue," *Fatigue and Fracture of Metals*, The Technology Press & John Wiley and Sons, Inc., p. 252.

(415) P. Litherland Teed, "Fatigue—What It Is and Some Ways of Reducing Its Incidence," *Shell Aviation News*, No. 172; *Aircraft Production*, Vol. 14, No. 169, p. 362.

(416) R. L. Templin, "Designing for Fatigue," *Fatigue and Fracture of Metals*, Technology Press & John Wiley and Sons, Inc., p. 131.

(417) R. L. Templin and E. C. Hartmann, "Designing for Repeated Loads," *Structures Memorandum No. 32*, Bur. Aeronautics.

(418) R. L. Templin and E. C. Hartmann, "How to Design for Repeated Loads," *Iron Age*, Vol. 169, p. 98.

(419) R. L. Templin, F. M. Howell, and J. O. Lyst, "Fatigue Properties of Cast Aluminum Alloys," *Product Engineering*, Vol. 23, p. 119.

(420) F. Vinsonneau, "The Utilization of High-Strength Light Alloys," *Technique et science aéronautiques*, Vol. 4, p. 205; *Metallurgical Abstracts*, Vol. 20, p. 686.

(421) P. B. Walker, "The Experimental Approach to Aircraft Structural Research," *Journal of the Aeronautical Sciences*, Vol. 19, No. 3 p. 145.

(422) K. Williams, "Fatigue Life of Wing Components for Civil Aircraft," *Journal*, Royal Aeronautical Soc., Vol. 56, No. 503, p. 842.

(423) H. A. Wills, "Structural Fatigue in Airline Safety," *Aircraft*, Vol. 30, No. 9, p. 18.

1953

(424) Anon., "The Shear, Fatigue, Bend, Impact and Long-Time Load Strength Properties of Structural Metal-to-Metal Adhesives in Bonds to 24S-T3 Aluminum Alloys," *Report No. 1836*, Forest Products Labs.; *Applied Mechanics Reviews*, Vol. 7, p. 202, item 1444.

(425) Anon., "N.B.S. Scientists Speak on Fracture," *Material & Methods*, Vol. 38, No. 1, p. 162.

(426) Anon., "Aircraft Design Through Service Experience," *Manual No. 103*, Civil Aeronautics Administration.

(427) Anon., "Adhesive Joints," *Aircraft Production*, Vol. 15, p. 402.

(428) V. I. Arkharov, S. I. Ignatyeva, and Yu. D. Kozmanov, "Thermal Fatigue of Single Crystals of Aluminum," *Doklady Akademii Nauk SSSR*, Vol. 88, p. 439; *Transaction No. NSF-tr-3*, Nat. Sci. Foundation.

(429) M. S. Binning and J. T. Ballett, "Fatigue Tests on Specimens from Aluminum Alloy DTD 683 'Z' Section Extrusions," *Technical Note No: Met. 179*, Royal Aircraft Establishment (British).

(430) A. P. Boresi and T. J. Dolan, "An Appraisal of the Prot Method of Fatigue Testing," *Technical Report No. 34, Research Project: The Behavior of Materials under Repeated Stress*, Univ. of Illinois.

(431) M. Bridgewater, "Aluminum As a Structural Material," *Engineering*, Vol. 175, p. 765.

(432) R. Cazaud, "Fatigue of Metals" (book), Chapman & Hall, Ltd. (London) (Fenner's translation).

(433) Charles B. Cliett, "Structural Comparison of Perforated Skin Surfaces with Other Means of Effecting Boundary-Layer Control by Suction," *Aeronautical Engineering Review*. Vol. 12, No. 9, p. 46.

(434) H. L. Cox, "Fatigue," *Journal*, Royal Aeronautical Soc., Vol. 57, p. 559.

(435) G. E. Dieter and R. F. Mehl, "Investigation of the Statistical Nature of the Fatigue of Metals," *Technical Note No. 3019*, Nat. Advisory Comm. Aeronautics.

(436) W. J. Fedyna, R. Schmidt, and J. Viglione, "Evaluation of Mechanical Properties and Welding Characteristics of XA78S Aluminum Alloy," *Report AML NAM AE 4124 (1) Part I*, Naval Air Material Center, Naval Base, Philadelphia, Pa.

(437) William N. Findley, "Combined-Stress Fatigue Strength of 76S-T61 Aluminum Alloy with Superimposed Mean Stresses and Corrections for Yielding," *Technical Note No. 2924*, Nat. Advisory Comm. Aeronautics.

(438) W. N. Findley, "Effect of Range of Stress on Fatigue of 76S-T61 Aluminum Alloy," *Journal of Applied Mechanics*, Vol. 20, No. 3, p. 365.

(439) G. Forrest, K. W. Gunn, and A. R. Woodward, "The Fatigue Properties of Z-Section Test Pieces Completely Machined from an Aluminum Alloy Extrusion Conforming to DTD 364B," *Journal*, Royal Aeronautical Soc., Vol. 57, p. 103.

(440) P. J. E. Forsyth, "Exudation of Material from Slip Bands at the Surface of Fatigued Crystals of an Aluminum-Copper Alloy," *Nature*, Vol. 17, p. 172.

(441) P. J. E. Forsyth and C. A. Stubbington, "The Influence of Substructure on the Slip Observed in Pure Aluminum and Some Aluminum Alloys When Subjected to Fatigue Stresses," *Report No: Met. 76*, Royal Aircraft Establishment (British).

(442) A. M. Freudenthal, "A Random Fatigue Testing Procedure and Machine," *Proceedings*, Am. Soc. Testing Mats., Vol. 53, p. 896.

(443) H. J. Grover, W. S. Hyler, Paul Kuhn, Charles B. Landers, and F. M. Howell, "Axial-Load Fatigue Properties of 24S-T and 75S-T Aluminum Alloy as Determined in Several Laboratories," *Technical Note No. 2928*, Nat. Advisory Comm. Aeronautics.

(444) Herbert F. Hardrath, Charles B. Landers, and Elmer C. Utley, "Axial-Load Fatigue Tests on Notched and Unnotched Sheet Specimens of 61S-T6 Aluminum Alloy, Annealed 347 Stainless Steel, and Heat-Treated 403 Stainless Steel," *Technical Note No. 3017*, Nat. Advisory Comm. Aeronautics.

(445) A. K. Head, "The Mechanism of Fatigue of Metals," *Journal of Mechanics and Physics of Solids*, Vol. 1, No. 2, p. 134.

(446) Hall L. Hibbard and J. F. McBrearty, "Structures for High Speed Aircraft," *Aviation Age*, Vol. 2, No. 5, p. 32.

(447) W. S Hyler, R. A. Lewis, and H. J. Grover, "Experimental Investigation of Notch-Size Effects on Rotating-Beam Fatigue Behavior of 75S-T6 Aluminum Alloy," *Report S-1922*, Battelle Memorial Inst.

(448) B. J. Lazan and A. A. Blatherwick, "Strength Properties of Rolled Aluminum Alloys Under Various Combinations of Alternating and Mean Axial Fatigue Stresses," *Proceedings*, Am. Soc. Testing Mats., Vol. 53, p. 856.

(449) B. J. Lazan, *et al.*, "Properties of Materials and Joints Under Alternating Force," *Status Report 53–6*, Inst. of Technology, Univ. of Minnesota.

(450) S. M. Marco and W. L. Starkey, "A Concept of Fatigue Damage," *Paper No. 53 A-143*, Am. Soc. Mechanical Engrs.

(451) M. J. McGuigan, Jr., "Interim Report on a Fatigue Investigation of a Full-Scale Transport Aircraft Wing Structure," *Technical Note No. 2920*, Nat. Advisory Comm. Aeronautics.

(452) G. Meikle, C. Braithwaite, and M. B. Binning, "Corrosion, Stress-Corrosion and Fatigue Tests on an Aluminum Alloy Having a High Young's Modulus," *Technical Note No: Met. 180*, Royal Aircraft Establishment (British).

(453) Dr.-Ing. A. Müller-Busse, "On the Endurance Limit of Welded Aluminum Alloys," *Aluminium*, Vol. 29, No. 3, p. 102.

(454) J. A. Nock, Jr., "Today's Aluminum Aircraft Alloys," *Transactions*, Soc. Automotive Engrs., Vol. 61, p. 209.

(455) G. M. Norris, "Effect of Mean Stress on the Fatigue Strength of DTD 364 Round Bars with and without Transverse Holes," *Current Paper No. 120*, Aeronautical Research Council (British).

(456) Henry Page, J. H. James, and F. S. Williams, "How Tough Are Nickel and Chromium Electroplating for Aluminum," *Product Engineering*, Vol. 24, No. 12, p. 162.

(457) A. Pomp, "Tests on Light Metal Riveted Joints," *Industrie-Anzeiger (Essen)*, Vol. 75, p. 213; *Light Metals Bulletin*, Vol. 15, No. 460, p. 333.

(458) F. R. Shanley, "Fatigue Analysis of Aircraft Structures," *Research Memorandum RM-1127*, PROJECT RAND, U. S. Air Force.

(459) Robert B. Shaw, "The Effect of $CuAl_2$ Dispersions on the Fatigue of Aluminum-Copper Alloys," *Twenty-sixth Technical Report, Series No. 22*, Univ. of California.

(460) G. M. Sinclair and T. J. Dolan, "Effect of Stress Amplitude on Statistical Variability in Fatigue Life of 75S-T6 Aluminum Alloy," *Transactions*, Am. Soc. Mechanical Engrs., Vol. 75, No. 5, p. 867.

(461) B. E. Stephenson, "Fatigue in Aircraft Design," *Journal*, Royal Aeronautical Soc. (British), Vol. 57, p. 584.

(462) W. D. Stewart, "Tolerances and Specifications for Aluminum and Magnesium Castings," *Mechanical Engineering*, Vol. 75, p. 450.

(463) Irving Stone, "Aircraft Makers Study Use of Redux," *Aviation Week*, Vol. 58, No. 14, p. 48.

(464) R. Syre, "Effect of Fabricating Processes and of Heat Treatment on the Properties of Heat Resistant Light Alloys," *Revue de métallurgie*, Vol. 50, No. 5, p. 311.

(465) Edward W. Thrall, Jr., "Fatigue Life of Thick-Skinned Tension Joints," *Aeronautical Engineering Review*, Vol. 12, No. 11, p. 37.

(466) H. A. Unckel, "Directionality Affects Physical Properties of Wrought Metals," *Iron Age*, Vol. 172, No. 11, p. 170.

(467) Georges Vidal, "Methods of Determining Hot Fatigue Limit in Common or Controlled Atmospheres," *Revue de métallurgie*, Vol. 50, p. 21.

(468) Gunnar Wallgren, "Direct Fatigue Tests with Tensile and Compressive Mean Stresses on 24S-T Aluminum Plain Specimens and Specimens Notched by a Drilled Hole," *Report No. 48*, Aeronautical Research Inst. of Sweden.

(469) I. Edward Wilks and Darnley M. Howard, "Effect of Mean Stress on the Fatigue Life of 24S-T3 and Alclad 75S-T6 Aluminum Alloys," *Technical Report No. 53-40*, Wright Air Development Center.

(470) Th. Wyss, "Influence of Testing Frequency on the Fatigue Strength of Steels and Light Alloys," ASTM BULLETIN, No. 188, p. 31.

1954

(471) Anon., "Aircraft Fatigue Tests at Farnborough," *Engineering*, Vol. 177, p. 132.

(472) Anon., "Alcoa Structural Handbook," Aluminum Co. of America.

(473) J. A. Bennett and J. G. Weinberg, "The Fatigue Notch Sensitivity of Some Aluminum Alloys," *Journal of Research*, Nat. Bureau Standards, Vol. 52, No. 5, p. 235.

(474) Paul Brenner, "Postwar European Progress in Wrought Aluminum and Its Alloys," *Metal Progress*, Vol. 61, No. 1, p. 112.

(475) P. Brenner and A. Mathing, "Investigation of the Strength of Glued Light Metal Joints," *Aluminium*, Vol. 30, p. 3.

(476) R. W. Bundy and Joseph Marin, "Fatigue Strength of 14S-T4 Aluminum Alloy Subjected to Biaxial Stresses," see p. 755 of this publication.

(477) R. A. Carl and T. J. Wegeng, "Concerning the Fatigue of Aircraft Structures," see p. 903 of this publication.

(478) H. T. Corten, Todor Dimoff, and T. J. Dolan, "An Appraisal of the Prot Method of Fatigue Testing," see p. 875 of this publication.

(479) H. T. Corten, G. M. Sinclair, and T. J. Dolan, "An Experimental Study of the Influence of Fluctuating Stress Amplitude on Fatigue Life of 75S-T6 Aluminum," see p. 737 of this publication.

(480) F. W. DeMoney and B. J. Lazan, "Dynamic Creep and Rupture Properties of an Aluminum Alloy Under Axial Static and Fatigue Stress," see p. 769 of this publication.

(481) I. D. Eaton and John A. Youra, "Additional Fatigue Tests on Effects of Design Details in 355-T6 Sand-Cast Aluminum Alloys," *Research Memorandum No. 53-L22*, Nat. Advisory Comm. Aeronautics.

(482) N. Enomoto, "On Fatigue Tests Under Progressive Stress, a Theory of Fatigue of Metals and a Quick Method for Determining the Fatigue Limit," presented at the Fifty-seventh Annual Meeting, Am. Soc. Testing Mats., June 13–18. To be published in 1955 ASTM *Proceedings*.

(483) W. N. Findley, W. I. Mitchell, and D. E. Martin, "Combined Bending and Torsion Fatigue Tests of 25S-T Aluminum Alloy," Technical Report No. 1 on Project to Determine: The Effect of Different States of Stress on the Fatigue of Materials with Corrections for Anisotropy; and the Basic Laws Governing Failure Under Combined Stress, Univ. of Illinois.

(**484**) G. Forrest, "Internal or Residual Stresses in Wrought Aluminum Alloys and Their Structural Significance," *Journal*, Royal Aeronautical Soc., Vol. 58, p. 261

(**485**) Herbert F. Hardrath and Walter Illg, "Fatigue Tests at Stresses Producing Failure in 2 to 10,000 Cycles. 24S-T3 and 75S-T6 Aluminum-Alloy Sheet Specimens with a Theoretical Stress-Concentration Factor of 4.0 Subjected to Completely Reversed Axial Load," *Technical Note No. 3132*, Nat. Advisory Comm. Aeronautics.

(**486**) E. C. Hartmann, Marshall Holt, and I. D. Eaton, "Fatigue Strength Butt Joints in $\frac{3}{8}$-in. Thick Aluminum Alloy Plates," *Welding Journal*, Vol 19, No. 1, p. 21s.

(**487**) Marshall Holt, "Some Factors Affecting the Fatigue Strength of Aluminum Alloy Sand Castings." *Preprint No. 54-29*, Am. Foundrymen's Soc.

(**488**) M. S. Hunter and W. G. Fricke, Jr., "Metallographic Aspects of Fatigue Behavior of Aluminum," see p. 717 of this publication.

(**489**) M. J. McGuigan, Jr., D. R. Bryan, and R. E. Whaley, "Fatigue Investigation of Full-Scale Transport-Airplane Wings. Summary of Constant-Amplitude Tests Through 1953," Appendix A, "Notes on the Use of Bonded Wires to Detect Fatigue Cracks," by M. H. Levin, *Technical Note No. 3190*, Nat. Advisory Comm. Aeronautics.

(**490**) R. E. Peterson, "Effect of Range of Stress on Fatigue of 76S-T61 Aluminum Alloy," *Journal of Applied Mechanics*, Vol. 21, p 91.

(**491**) N. H. Polakowski and A. Palchoudhuri, "Softening of Certain Cold-Worked Metals Under the Action of Fatigue Loads," see p. 701 of this publication.

(**492**) R. J. Rooney, "Investigation of Skin Effect on the Axial Loading Fatigue Properties of Thin Extrusions of Aluminum Alloys," *Technical Note No. WCRT 53-206*, Wright Air Development Center.

(**493**) Ira Smith, Darnley M. Howard, and Frank C. Smith, "Cumulative Fatigue Damage of Axially Loaded Alclad 75S-T6 and Alclad 24S-T3 Aluminum Alloy Sheet," *Project No. W-5364*, Nat. Advisory Comm. Aeronautics, Nat. Bureau Standards.

(**494**) C. O. Smith, "Mechanical Properties of Aluminum Die Casting Alloys," *Preprint No. 54-24*, Am. Foundrymen's Soc.

(**495**) C. R. Smith, "Prediction of Fatigue Failure in Aluminum Alloy Structures," presented before Spring Meeting of Soc. for Experimental Stress Analysis. To be published in *Proceedings*, Soc. for Experimental Stress Analysis.

(**496**) R. Tondreau, "Extruded Integrally Stiffened 75S-T6 Aluminum Alloy Sheet Fatigue Strength," *Technical Note No. WCRT 53-131, Addendum 1*, Wright Air Development Center.

(**497**) Georges Welter and Andre Choquet, "Stress Distribution and Fatigue Resistance of Alclad 24S-T Multiple Spot Welds," *Welding Journal*, Vol. 33, No. 2, p. 91s.

SUMMARY OF PROCEEDINGS OF THE SYMPOSIUM ON EFFECT OF CYCLIC HEATING AND STRESSING ON METALS AT ELEVATED TEMPERATURES

Sessions Twenty-seven and Twenty-eight of the Fifty-seventh Annual Meeting of the Society held in Chicago, Ill., on June 17, 1954, were devoted to the Symposium on Effect of Cyclic Heating and Stressing on Metals at Elevated Temperatures. It was sponsored by the Joint Committee on Effect of Temperature on the Properties of Metals. Of the eight papers, two cover various theoretical aspects, three discuss creep and rupture data, two present intermittent load and temperature data, and the final paper deals with the effect of cyclic temperature on the scaling behavior of heat-resisting alloys.

The following papers were presented:

Introduction—D. N. Frey
What We Need to Know About Creep—John E. Dorn and Lawrence A. Shepard
The Problem of Thermal Stress Fatigue in Austenitic Steels at Elevated Temperatures—L. F. Coffin, Jr.
Effect of Temperature Cycling on the Rupture Strength of Some High-Temperature Alloys—James Miller
Experiments on the Effects of Temperature and Load Changes on Creep Rupture of Steels—G. V. Smith and E. G. Houston
Effects of Cyclic Overloads on the Creep Rates and Rupture Life of Inconel at 1700 and 1800 F—R. H. Caughey and W. B. Hoyt
The Creep-Rupture Properties of Aircraft Sheet Alloys Subjected to Intermittent Load and Temperature—G. J. Guarnieri
Constant and Cyclic-Load Creep Tests of Several Materials—Ward F. Simmons and Howard C. Cross
The Effect of Composition on the Scaling of Fe-Cr-Ni Alloys Subjected to Cyclic Temperature Conditions—H. E. Eiselstein and E. N. Skinner
Summary—D. N. Frey

The papers and discussions were issued as *ASTM Special Technical Publication No. 165* entitled "Symposium on Effect of Cyclic Heating and Stressing on Metals at Elevated Temperatures."

SOFTENING OF CERTAIN COLD-WORKED METALS UNDER THE ACTION OF FATIGUE LOADS†*

By N. H. Polakowski[1] and A. Palchoudhuri[2]

Synopsis

There is a widespread belief that fatigue of ductile metals is invariably associated with progressive strain-hardening. Although this is true for initially unstrained metals, the results now reported show that with initially cold-worked metals the opposite is more likely to be the case. Instead of becoming work-hardened still further compared with the initial condition, such metals may soften gradually under the action of fatigue loads.

In these experiments, copper, nickel, aluminum, and three of their alloys as well as a nonaging titanium-killed steel were first cold-drawn 20 to 40 per cent to 0.2 in. in diameter and later were subjected to alternating tension-compression fatigue stressing at frequencies from 5500 to 9500 cpm. Compression tests and Vickers hardness determinations on the fatigued specimens showed more or less pronounced softening in each case.

These observations are discussed in the light of previous work on the Bauschinger effect and its manifestations. An interpretation of the present findings is offered on a pure stress-strain basis. It is suggested that fatigue failure of a cold-worked metal may be attributed to the breakdown of the initially high elastic properties under cyclic strain and to the semi-plastic behavior developed thereby. The cyclic plastic flow would facilitate the coalescence of vacant lattice sites into larger holes, which may act as crack embryos.

It has been long recognized that fatigue failure of a ductile metal is a consequence of repeated plastic movements (slip) inside the crystalline structure (**1, 2**).[3] This thoroughly proven fact provided the physical basis for different theories of fatigue advanced during the past half century. It is notable that it was commonly assumed in these theories that failure by fatigue is accompanied by, or is a consequence of, progressive work-hardening (**3, 4, 5**). For instance, Orowan's semiquantitative theory (**6**) with its zig-zag diagrams relied explicitly upon the universal validity of this basic concept. The same assumption was made by Afanasiev (summarized in (**7**)) and more recently by Freudenthal and Dolan (**8**).

However, a reference to the various

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† Presented at the Fifty-seventh Annual Meeting of the Society, June 13–18, 1954.

* This investigation was carried out at the Metallurgical Department, University College of Swansea, Great Britain.

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[3] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 712.

sources just enumerated indicates that the assumption was based exclusively on experience gained from fatigue tests on initially soft metals, that is, hot-worked or annealed. Such metals were found to harden slightly under the action of alternating stress cycles; their originally low elastic limits, yield points, indentation hardness numbers, and, to a lesser extent, tensile strength values were increased when compared with the unstrained condition (**9–12**).[4]

So far as the permanent changes caused by cyclic strains in initially cold-worked metals are concerned, previous investigations were mainly devoted to X-ray studies (**13–16**). Their results seemed to indicate some retrogression of the work-hardened condition, the originally blurred diffraction rings again becoming sharp after cyclic stressing.

Static mechanical tests were seldom employed for this purpose, and it appears that only Czochralski and Henkel (**10**) have published somewhat systematic tension test results on fatigued aluminum, copper, and iron in both the annealed and cold-drawn condition. There was a conspicuous difference between the two sets of results. The proportional and yield limits (0.001, 0.01, and 0.2 per cent offset) of the annealed specimens rose significantly in proportion to the stress amplitude or the number of cycles applied. On the other hand, and disregarding the rather considerable scatter of the resultant points, the tensile properties of the as-drawn materials remained essentially unaffected by the fatigue stressing. It may be pointed out in this connection that the utilization of a rotary bending fatigue tester in the above work (**10**) was perhaps unfortunate since the maximum cyclic strain was imposed only on the outer skin, the interior of the specimen remaining relatively little affected. In that way any characteristic changes brought about by fatigue were "diluted" and could not be detected in the subsequent tension test, especially in view of the experimental scatter referred to above.

A number of other researches were concerned with the effect of fatigue on the residual stresses left in steel and in one or two other metals after preceding cold deformation or heat treatment (**17**). These have shown that the residual stresses fade away under the influence of cyclic stresses, thus indicating that fatigue is accompanied by plastic flow. It seems unlikely that the latter should leave the structure of the metal unaffected and that the static properties before and after cycling should be the same.

It was thus the purpose of this work to re-examine the effect of fatigue loads upon the static mechanical properties of several common metals in the cold-worked condition. In order to accentuate such changes as may possibly occur, alternating tension-compression stressing was employed instead of reversed flexure. Since incipient fatigue cracks were likely to influence the tensile properties and to obscure the actual changes in the matrix outside the crack area, the tension test was replaced by compression and hardness tests. The types of stresses generated in a metal cylinder by axial compression are such that the over-all resistance to compression is hardly affected by micro- or even macrocracks appearing substantially under right angles to the specimen axis. All the experiments were performed on rods in the as-drawn condition, thereby securing identical systems of residual stresses in each series of specimens.

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[4] Carbon steel with a well-developed discontinuous yield represents in one respect an exception from this rule: its yield point is being depressed by fatigue stressing in spite of the fact that its matrix becomes distinctly harder (**9, 11, 13**). This peculiarity will be disregarded in this paper as being of secondary importance for the general argument of the present work which is concerned solely with metals showing a smooth, continuous extension curve in the annealed condition.

Although caution must be exercised before applying the following evidence to metals other and more complex than those investigated, the results reported indicate that initially work-hardened metals soften rather than harden still further under the action of fatigue strains. Their behavior is thus analogous to that of hard-drawn or rolled products which were straightened by reversed bending (**18**).

TABLE I.—LIST OF MATERIALS USED IN THE EXPERIMENTS.

	Copper A[a]	95-5 Tin-Bronze	80-20 Cupro-Nickel	Nickel "O"	Aluminum (99.0 per cent Al)	Al + 1.2 per cent Mn Alloy	0.12 per cent C, 0.72 per cent Ti Steel
			CONDITION: AS-DRAWN				
Symbol	C1-41	C3-32	C4-27	N1-20	A1-36	A2-36	T1-39
Cold-drawn, per cent	40.6	31.5	27.3	20[b]	35.9	35.9	39.0
Diameter, in.	0.200	0.189	0.201	0.200	0.200	0.200	0.199
Tensile strength, psi	56 000	88 200	85 100	70 300	20 000	22 800	76 400
Elongation in 4 in., per cent	3.8	5.9	2.5	5.5	7.7	3.9	4.8
			CONDITION: ANNEALED				
Symbol	C1-0	C3-0	...	N1-0	...	...	...
Annealing temperature, deg Cent	600	600	...	750	...	...	...
Annealing time, hr	½	½	...	½	...	...	...
Tensile strength, psi	32 200	51 300	...	55 500	...	...	...
Elongation in 4 in., per cent	47.8	63.0	...	39.3	...	...	...

[a] Copper B from different supplier and drawn 27.6 per cent gave results (not reproduced) similar to the A quality.

[b] Estimated value; material described by supplier as "half-hard."

EXPERIMENTAL MATERIALS AND PROCEDURE

Materials:

In order to avoid any disturbing effects caused by aging phenomena, only single phase, nonaging metals and alloys were used. Of these, the 95-5 phosphor-bronze and the "nonaging" 0.12 per cent carbon, 0.72 per cent titanium steel nevertheless did occasionally show certain aging features in the form of a small yield serration. However, since this occurred only after plastic extension (but not after cold-drawing) and outside the range of temperatures which were observed in these experiments, the phenomenon was of no practical significance in this work.

The available fatigue testing machine could accommodate both screw-headed and straight wire specimens up to 0.2 in. in diameter. For the reasons already explained, cold-drawn rods (annealed when necessary) were used throughout Details of the materials are contained in Table I.

Cyclic Stressing:

Cyclic stressing was carried out on an Amsler "Vibrophore" tension-compression fatigue tester of ±1 metric ton load capacity and a frequency range of about 5000 to 10,000 cpm.[5] The free length of the specimen between the grip faces was 0.75 in. A frequency of about 5500 cpm was used in most tests, but with materials C1-0, A1-36, and

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[5] A description of the machine is given on p. 85 of Cazaud's book (**19**).

A2-36 the maximum attainable speeds of 9200 cycles per min for copper and 7800 for aluminum were employed. It has been found that with these relatively soft metals the machine could be adjusted and operated more easily at top speed setting.

The specimens were normally fastened in the gripping heads on a special jig supplied with the machine in order to eliminate misalignment and consequent bending of the rods during clamping. However, since the two relatively heavy heads (about 3 lb each) were held together by the slender 0.2-in. diameter specimen, it was not always easy to prevent some of the softest test rods from being bent accidentally during the transfer of the assembled test unit from the jig to the fatigue machine. This difficulty was obviated by fitting one end only of the soft copper or aluminum rod into the head outside the machine, the other end being left unmounted. Both gripping heads were then fixed on the machine, and the lowering and tightening-up of the upper head on the projecting end of the test rod was done *in situ*.

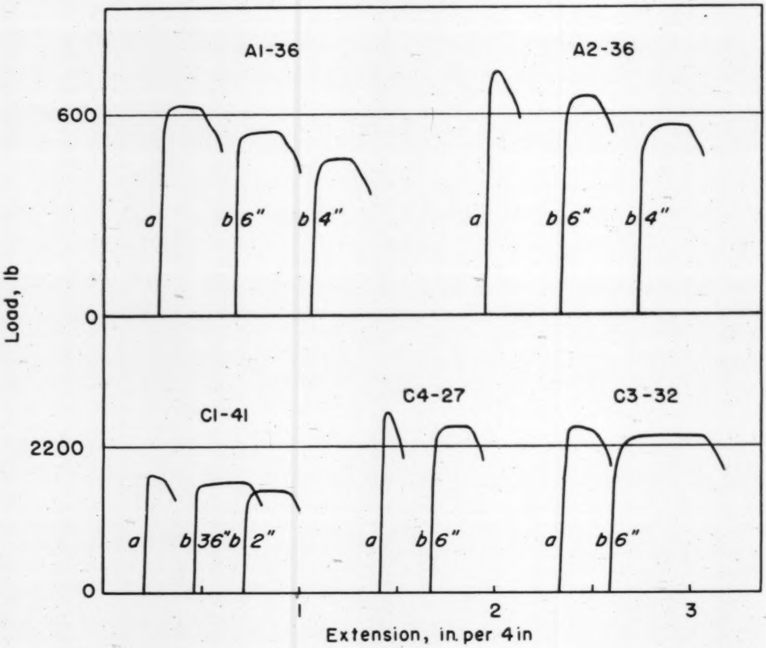
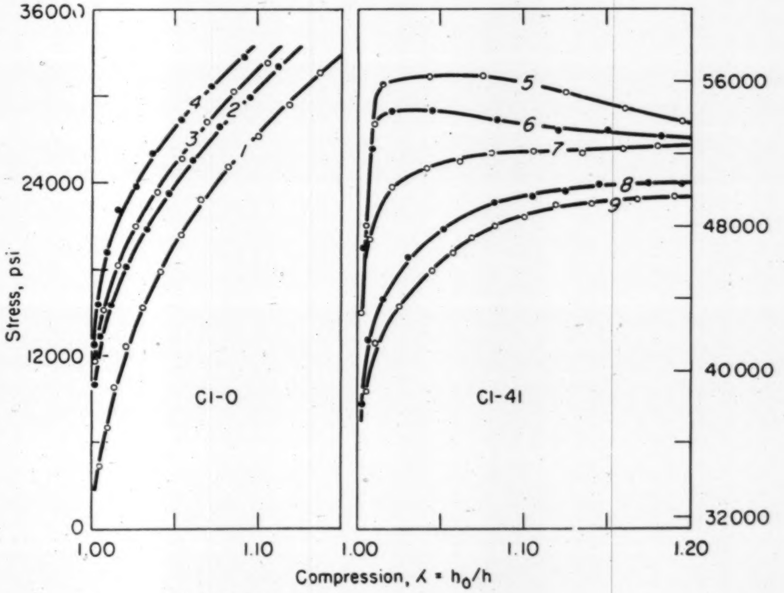


FIG. 1.—The Effect of Four Reversed Bending Cycles on Tensile Properties of Some of the Experimental Materials in the As-Drawn Condition. *a*—As-drawn; *b*—after reversed bending over the diameters indicated.

Some of the fatigue runs were performed at a constant amplitude but with different numbers of cycles applied to each specimen in one series. Alternatively, the stress was varied from one test to the other while the number of cycles remained approximately constant. Each series consisting of 4 to 6 specimens cut from the same rod was carried out at least in duplicate, but usually in triplicate.

Compression Tests:

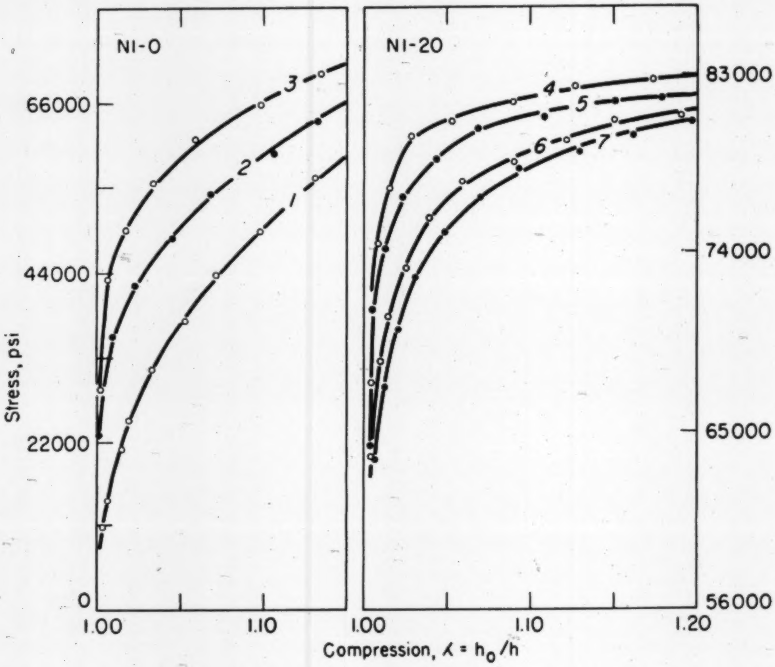
Some of the reasons for the preference given in this work to compression tests were indicated above. This testing method has also the advantage of excellent reproducibility, all the different readings obtained from several similar specimens falling smoothly on a single curve, practically without scatter. Furthermore, a compression test can be made with ease on a portion of a specimen that fractured in the course of a fatigue run since a small cylinder can be cut off from one of the two halves of the broken sample. Finally, in view of the small dimensions of the active part of the fatigued rods in these tests (0.75 by 0.2 in.), accurate and reproducible tension tests on them would have been difficult to perform.



Curve 1—as annealed
2—annealed + 20,000 cycles of ±7370 psi
3—annealed + 250,000 cycles of ±7370 psi
4—annealed + 28,000 cycles of ±10,400 psi
5—as drawn
6—drawn + 6000 cycles of ±28,500 psi
7—drawn + 273,000 cycles of ±28,500 psi
8—drawn + 83,000 cycles of ±29,400 psi
9—drawn + 317,000 cycles of ±29,400 psi

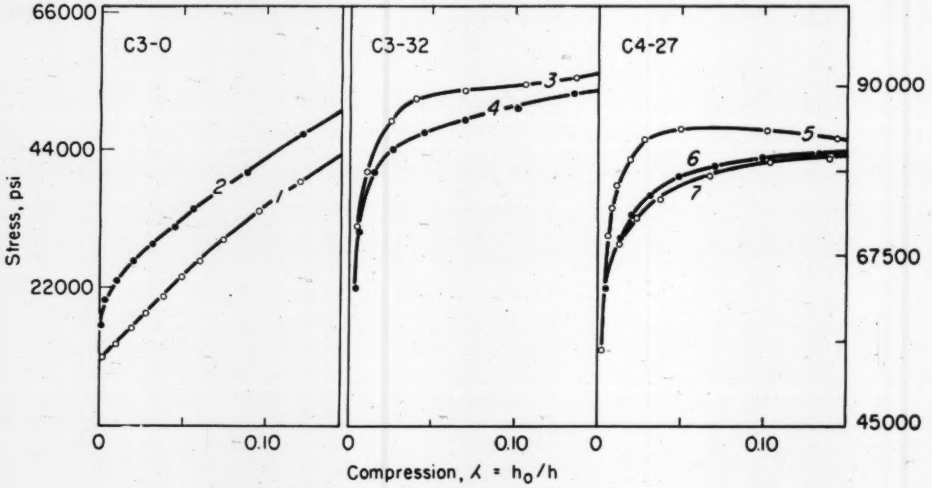
FIG. 2.—The Effect of Alternating Tension-Compression Fatigue Stresses on Static Compression Properties of Annealed (Curves 1 to 4) and Cold-Drawn (Curves 5 to 9) Copper.

When cyclic prestressing was completed, the specimen was removed from the fatigue tester and its central, active portion was sawed off carefully. The ends were faced on a small precision lathe and then finished on 0 polishing paper. In this way a small cylinder was obtained, its height being about twice its diameter. This was compressed in small stages on a hand-operated Amsler weight pendulum machine by using 0.5, 1, or 2.5 ton (1 ton = 2240 lb) load ranges, depending on the material tested. The ends of the specimen were greased after each load application with a commercial mixture of fine graphite



Curve 1—as annealed
2—annealed + 280,000 cycles of ±21,900 psi
3—annealed + 38,000 cycles of ±30,600 psi
4—as drawn
5—drawn + 3,125,000 cycles of ±32,000 psi
6—drawn + 100,000 cycles of ±43,700 psi
7—drawn + 237,000 cycles of ±43,700 psi

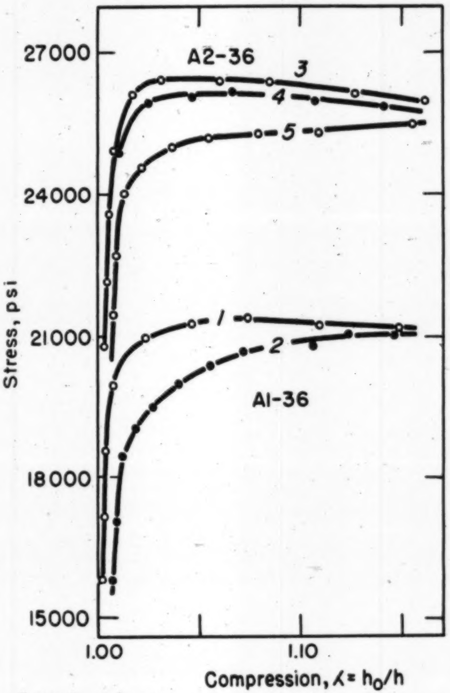
FIG. 3.—The Effect of Alternating Tension-Compression Fatigue Stresses on Static Compression Properties of Annealed (Curves 1 to 3) and Cold-Drawn (Curves 4 to 7) Nickel.



Curve 1—as annealed
2—annealed + 473,000 cycles of ±25,500 psi
3—as drawn
4—drawn + 73,000 cycles of ±57,300 psi
5—as drawn
6—drawn + 86,000 cycles of ±48,600 psi
7—drawn + 102,000 cycles of ±51,500 psi

FIG. 4.—The Effect of Alternating Tension-Compression Fatigue Stresses on Compression Properties of Annealed or Cold-Drawn Phosphor-Bronze (Curves 1 to 4) and Cold-Drawn Cupro-Nickel (Curves 5 to 7).

powder and castor oil. The load was kept on the specimen for 1 min, and the height of the cylinder was measured by means of a 25-mm micrometer with 0.01-mm graduations. Identical tests were performed on the same metals in the as-drawn (or annealed) condition, without subjecting them to alternating stressing.



Curve 1—as drawn
2—drawn + 192,000 cycles of ±13,200 psi
3—as drawn
4—drawn + 50,000 cycles of ±14,600 psi
5—drawn + 41,000 cycles of ±16,100 psi

FIG. 5.—The Effect of Alternating Tension-Compression Fatigue Stresses on Static Compression Properties of Cold-Drawn Commercial Aluminum and an Aluminum + 1.2 per cent Manganese Alloy.

From the initial cross-sectional area and the measured loads and heights, it was possible to compute the actual or "true" compressive stress. As a measure of deformation the ratio $h_0 : h$ (initial height : instantaneous height of specimen) was employed throughout. From this ratio, the percentage compression can be calculated as $100 \times (\lambda - 1)/\lambda$, in which $\lambda = h_0 : h$. The logarithmic or "true" strain is $\epsilon = \ln \lambda$.

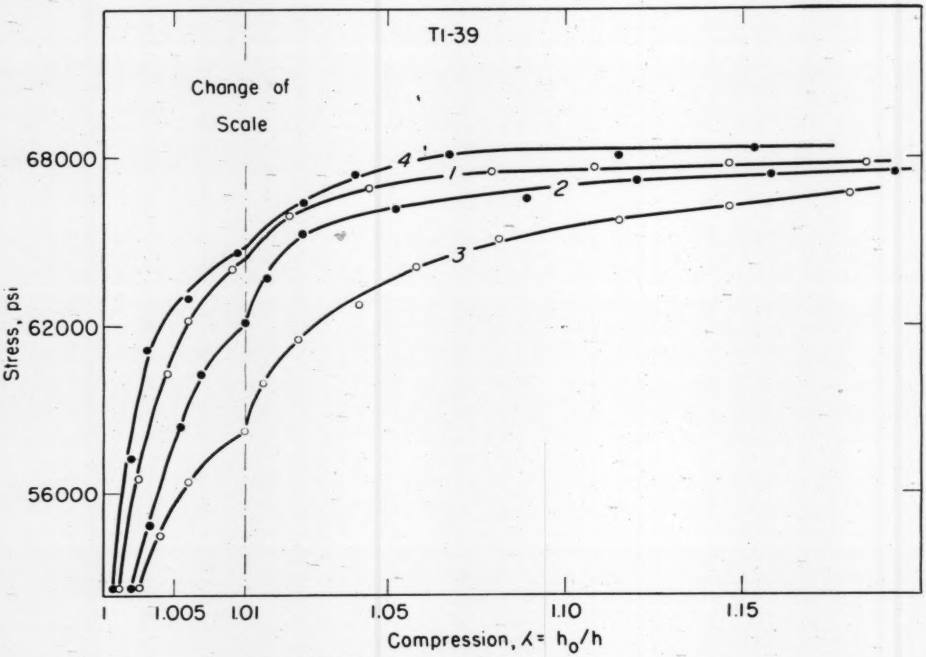
EXPERIMENTAL RESULTS

Before commencing the main experiments, exploratory tests were performed on the available metals. These tests consisted in bending the cold-drawn materials several times to and fro over cylinders of 1.75 to 36-in. diameter and pulling them to fracture afterwards. A selection of the extensometer records obtained is shown in Fig. 1.

As could be expected (18) the reversed bending treatment resulted in an appreciable depression of the stress values at which large plastic deformations began. In most cases this change was accompanied by an increase of the elongation to fracture.

There was no obvious reason to anticipate that fast stress reversals should give fundamentally different results from those above. This expectation was confirmed by all the experiments made, as will be seen from the selection of typical compression diagrams shown in Figs. 2 to 6.

Even though differing in magnitude from one metal to the other, the effect of an application of a sufficient number of stress repetitions was always in the direction of reducing the resistance to subsequent plastic compression. Particularly conspicuous changes can be observed on copper (C1-41), nickel (N1-20), and the titanium steel (T1-39). Due to the limitations of the equipment it was not possible to follow up with sufficient accuracy the stress-strain relations in the elastic-plastic range around and below 0.1 per cent compression. It has been observed, however, that the as-drawn specimens showed very little creep under static load and a virtually steady condition was reached quickly. The drawn and afterwards "cycled" metals behaved differently and exhibited substantial creep throughout the static test even at low loads. This creep did not approach even a reasonable standstill after the 1-min period provided for each load application.



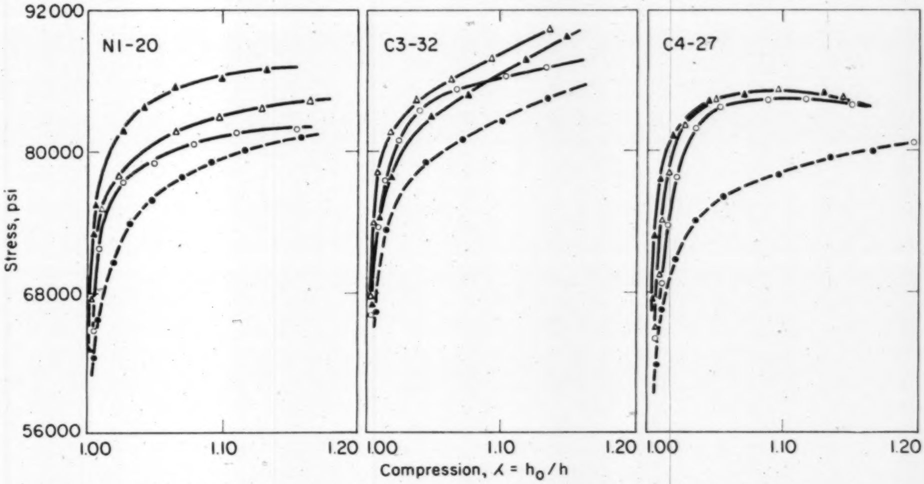
Curve 1—as drawn
2—drawn + 50,000 cycles of ±48,100 psi
3—drawn + 9000 cycles of ±51,300 psi
4—drawn + heated at 500 C for 1 hr

FIG. 6.—The Effect of Alternating Tension-Compression Fatigue Stresses and of a Low-Temperature Heat Treatment on Static Compression Properties of a Cold-Drawn Low-Carbon Titanium Steel.

As opposed to the softening effect of fatigue on initially hard-drawn metals, the application of a similar treatment to the same metals in the soft-annealed condition invariably resulted in strain-hardening. This is clearly demonstrated by the sequence of the compression curves of materials C1-0 (Fig. 2), N1-0 (Fig. 3), and C3-0 (Fig. 4), and the observation agrees with all previous evidence.

Irrespective of whether the metal was initially annealed or cold-worked, the change of the static stress-strain properties was the more pronounced the larger the number of cycles applied and the higher the cycle amplitude. Of these two factors the amplitude was the more potent, and a small alteration of the cyclic stress range was more critical for the final effect than varying the number of cycles over quite a wide range.

The cyclic stress amplitudes were normally unsafe but, with a few exceptions, the numbers of stress applications in the different fatigue runs were not sufficient to result in a complete fracture. Also, the thermal effect due to the dissipated damping energy was usually small. Only the cupro-nickel (C4-27) and the titanium steel (T1-39) showed considerable heating, and whenever the temperature of the specimen rose to 100 to 120 C, the machine was temporarily stopped to allow the metal to cool down.



Condition of material: ○—as drawn; ●—drawn and fatigued (maximum softening); △—drawn and heated at 150 C for 2 hr; ▲—drawn and heated at 220 C for 2 hr.

FIG. 7.—Comparison of the Relative Effects of Low-Temperature Heat Treatment and of Fatigue Stressing on Compression Properties of Cold-Drawn Nickel (N1-20), Bronze (C3-32), and Cupro-Nickel (C4-27).

TABLE II.—CHANGES OF VICKERS HARDNESS (DPH) OF THE COLD-DRAWN RODS CAUSED BY FATIGUE STRAINS.

	A1-36	A2-36	C1-41	C3-32	C4-27	N1-20	T1-39
Indenting load, kg	2.5	2.5	5	10	10	10	10
Diamondy pramid hardness, as drawn	40.0	46.5	118	191	155	187	190
Diamond pyramid hardness after cyclic strain (maximum softening)	37.5	43.5	97	188	148	164	174

In order to assess the possible effect of a moderate temperature increase of the specimen upon its compression properties at room temperature, a low-temperature heat treatment of 2-hr duration was applied to some of the experimental metals. The appropriate compression curves shown in Figs. 6 and 7 indicate that such heating tended to increase rather than reduce the resistance to compression and could not account for the observed softening of the work-hardened materials.

Finally, a number of Vickers diamond hardness tests was performed on the specimens before and after cycling. The main results are summarized in Table II, each value representing an average of ten readings taken at random on the periphery of the specimen. These figures again confirm that the drawn rods were softened by the fatigue loads to a greater or lesser extent.

DISCUSSION

Based on the concepts in a previous paper (18), the reported findings may thus be interpreted in the following manner:

An alternating stress which is accompanied by plastic flow produces in an initially unstrained metal certain structural changes, the extent of these changes being determined by the type of loading (direct stresses, reversed flexure, or torsion) and its amplitude. These changes are progressive and they lead eventually to a certain limiting work-hardened condition. This condition is attained after a finite number of load cycles and, due to the Bauschinger effect, it does not alter afterwards except for reversible, noncumulative variations.

It is now postulated that stress cycles of a given type and amplitude should tend to produce a specific condition (as defined above) irrespective of the initial work-hardened condition of the metal being fatigued. Thus, for fixed cycle parameters, an initially soft material must gradually work-harden until a definite final hardness level is attained. However, if the same metal was initially cold worked by some static method to a hardness level higher than the preceding maximum, then the same cyclic stress could result only in a softening effect. From the above it does not necessarily follow that a heavily strain-hardened metal must soften to such an extent as to reach a "limiting condition" appropriate for some comparatively low amplitude of alternating stress. The effect actually observed in this work was much less than that, but a definite trend in the right direction could be clearly recognized.

As long as the fatigue stress applied to a cold-worked metal is much lower than the static yield stress, the plastic component of each cycle is very small and so are the attendant structural changes. In effect the rate of softening is very small indeed, if at all detectable. With increasing amplitude of the cyclic stress, the plastic component grows rapidly and the rate of softening is thus enhanced, the resultant depression of the static yield point becoming more conspicuous. This explains why more softening is obtained when the cyclic stress amplitude is increased and also why an increase of the number of cycles of constant amplitude has less influence in this respect.

It has been suggested in the previous paper (18) that the relatively small improvement of fatigue strength achieved by cold-working of various single-phase metals and alloys (mainly non-ferrous) may be due to their gradual softening under fatigue loads.

Quite recently, Hempel and Houdremont of the Max-Planck Institute at Düsseldorf followed independently an identical path of thought, after having found that progressive cold working by increasing amounts of stretching does not raise the fatigue limit of a titanium-stabilized 15-27 type chromium-nickel steel (16). The possibility of gradual softening of this stable austenitic material was considered but no positive proof to this end could be obtained from comparison of the tensile strengths before and after fatigue. However, those authors admitted that the last results were inconclusive, and further work on these lines was contemplated.

The behavior of the 15-27 steel was in marked contrast to that of two carbon steels and of an 18-8 type unstable austenitic steel, where prestretching resulted in a substantial increase of the fatigue strength. With this in view, it is plausible to assume that the improved fatigue properties could primarily be a result of strain-aging in the carbon steels and of the $\gamma \rightarrow \alpha$ transformation in the 18-8 alloy, since both of these factors act in the direction of strengthening the metal independently from the net effects of the cold-working process.

On the whole, the experiments reported in the present paper seem to support the contention that cold working by itself may be of lesser importance in raising the fatigue limit of a metal than the attendant, extraneous effects (such as strain-aging or phase transformation). However, even at its best, the existence of the softening phenomenon may represent a necessary but not a sufficient condition for the soundness of the above idea. Further experiments are needed in order to determine in the first place whether or not the incidence of strain-softening is associated only with cyclic stresses in excess of the fatigue limit. If circumstances permit, work along these lines may be undertaken in the future.

CONCLUSIONS

The old hypothesis associating a fatigue failure of a ductile metal with extreme strain-hardening in certain micro-regions of the matrix was never supported by direct experimental proof. It represented rather an arbitrary, though plausible extrapolation and generalization of the fact that ductile metals in the soft condition become work-hardened to a limited extent when subject to fatigue stressing. The present results neither support nor positively controvert this concept insofar as initially soft metals are concerned. They do indicate, however, that it is very unlikely to apply in the case of originally cold-worked materials since the latter show a distinct over-all softening under fatigue loads. The idea that a general softening may nevertheless be accompanied by "extreme strain-hardening" in some isolated regions appears to be very farfetched indeed.

It is suggested that in the second case a fatigue fracture is originated as a result of the gradual breakdown under cyclic strain of the initially high elastic (or quasi-elastic) properties acquired by the metal as the result of initial cold-working. Consequently, the plastic component of the cycle increases gradually instead of being attenuated. Under these circumstances the initiation of the fatigue crack is evidently associated not with exhaustion of ductility (or plasticity) by progressive work-hardening but rather with the semiplastic condition developed by the action of the alternating strains.

It seems probable that the increased mobility of the elements of the atomic fabric of the metal enables various vacant lattice sites existing inside the crystalline structure to migrate and accumulate gradually until they form relatively large voids (20). The gradual growth of such voids to a size of a crack embryo can be well visualized without the necessity of postulating strain-hardening effects in its immediate surroundings.

The question of whether or not fatigue is accompanied by partial recrystallization (21, 22) does not appear to be of basic importance for the mechanism suggested above. If it does occur in certain isolated cases (22), it may well represent an incidental rather than fundamental factor in fatigue.

Acknowledgment:

The authors wish to express their thanks to Hugh O'Neill, Head of the Metallurgical Department, University College of Swansea, for facilities, encouragement, and helpful discussion. The experimental materials were generously presented through the kind services of F. T. Cleaver and W. J. Bannister (British Insulated Callender's Cables Ltd., Prescott), M. Cook and E. C. Larke (I.C.I. Metals Division, Birmingham), H. W. G. Hignett (The Mond Nickel Co., Ltd., Birmingham), and A. Morris (Aluminum Wire and Cable Co., Ltd., Swansea).

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REFERENCES

(1) W. Rosenhain, "Introduction to Physical Metallurgy," Constable & Co., London (1915).

(2) H. J. Gough, "Crystalline Structure in Relation to Failure of Metals—Especially by Fatigue," *Proceedings*, Am. Soc. Testing Mats., Vol. 33, Part II, p. 3 (1933).

(3) H. J. Gough and D. Hanson, "The Behavior of Metals Subjected to Repeated Stresses," *Proceedings*, Royal Soc. (London), Vol. 104-A, p. 538 (1923).

(4) M. Gensamer, "General Survey of the Problem of Fatigue and Fracture," in "Fatigue and Fracture of Metals" (symposium, W. M. Murray, editor), Massachusetts Institute of Technology and John Wiley and Sons, Inc., New York, N. Y., p. 1 (1952).

(5) P. L. Teed, "The Influence of Metallographic Structure on Fatigue," *ibid.*, p. 252.

(6) E. Orowan, "Theory of Fatigue of Metals," *Proceedings*, Royal Soc. (London), Vol. 171-A, p. 79 (1939).

(7) N. A. Shaposhnikov, "Mechanical Testing of Metals," Mashgiz, Moscow-Leningrad (1951).

(8) G. M. Sinclair and T. J. Dolan, "Use of a Recrystallization Method to Study the Nature of Damage in Fatigue of Metals," *Proceedings*, First U. S. National Congress of Applied Mechanics, J. W. Edwards, Ann Arbor, Mich., p. 647 (1952).

(9) H. F. Moore and J. B. Kommers, "The Fatigue of Metals," McGraw-Hill Book Co., Inc., New York, N. Y. (1927).

(10) J. Czochralski and E. Henkel, "Welche Veränderungen erleiden die mechanischen Eigenschaften durch Ermüdung?" *Zeitschrift für Metallkunde*, Vol. 20, p. 58 (1928).

(11) K. Memmler and K. Laute, "Dauerversuche an der Hochfrequenz-Zug-Druck-Maschine, Bauart Schenck," *Forschungsarbeiten a.d. Gebiete des Ingenieurwesens* (*V.D.I.*), No. 329 (1930).

(12) G. Welter, "Rotary Bending and Alternating Tension-Compression Fatigue Tests," *Wiadomosci Instytutu Metalurgii i Metaloznawstwa* (*Warsaw*), Vol. 4, No. 1, p. 30 (1937).

(13) H. J. Gough and W. A. Wood, "Deformation and Fracture of Mild Steel Under Cyclic Stresses in Relation to Crystalline Structure," *Proceedings*, Inst. Mechanical Engrs., Vol. 141, p. 175 (1939).

(14) F. Körber, "Das Verhalten metallischer Werkstoffe im Bereich kleinen Verformungen," *Proceedings*, Fifth International Congress for Applied Mechanics, Cambridge, Mass., p. 20 (1938); *Stahl und Eisen*, Vol. 59, p. 618 (1939).

(15) C. S. Barrett, "Structure of Metals," McGraw-Hill Book Co., Inc., New York, N. Y. (1943).

(16) M. Hempel and E. Houdremont, "Beitrag zur Kentniss der Vorgänge bei der Dauerbeanspruchung von Werkstoffen," *Stahl und Eisen*, Vol. 73, p. 1503 (1953).

(17) O. J. Horger and H. R. Neifert, "Internal Stresses and Fatigue," in "Fatigue and Fracture of Metals" (symposium, W. M. Murray, editor), Massachusetts Institute of Technology and John Wiley and Sons, Inc., New York, N. Y., p. 103 (1952).

(18) N. H. Polakowski, "Restoration of Ductility of Cold-Worked Aluminum, Copper, and Low-Carbon Steel by Mechanical Treatment," *Proceedings*, Am. Soc. Testing Mats., Vol. 52, p. 1086 (1952); *Nature*, Vol. 171, p. 173 (1953).

(19) R. Cazaud, "Fatigue of Metals," Philosophical Library, New York, N. Y. (1953).

(20) J. N. Greenwood, "Intercrystalline Cracking of Metals," *Journal*, Iron and Steel Inst., Vol. 171, p. 380 (1952).

(21) U. Dehlinger, "Structural Changes in Metals at Fatigue Fracture," *Metallwirtschaft*, Vol. 10, p. 26 (1931).

(22) J. N. Kenyon, "The Reverting of Hard-Drawn Copper to the Soft Condition Under Variable Stress," *Proceedings*, Am. Soc. Testing Mats., Vol. 50, p. 1071 (1950).

DISCUSSION

Mr. George R. Gohn.[1]—There are many theories on the mechanism of fatigue, most of which have been discarded. Probably the one which is most widely held by people working in the field of fatigue today is the theory of progressive strain-hardening as a result of slip and work-hardening. However, this theory does not explain all of the observed phenomena.

In a paper presented before this Society by J. N. Kenyon on rotating-beam tests on copper wire,[2] he reported that he had found islands of a soft material in a harder matrix when he performed fatigue tests on hard-drawn copper wire. The present authors have shown that these conditions prevail not only in copper but in other materials as well.

In explanation of this, the closing sentence of the authors' synopsis postulates a hypothesis which is held by physicists today, namely, that fatigue can be explained in terms of dislocations. The dislocations tend to pile up at discontinuities, at imperfections in the metal, at inclusions, or even in structures where there are hard and soft grains. The difference in hardness of these grains may provide the obstruction against which the dislocations pile up, and this eventually leads to fatigue failure.

Further exploration of the author's findings might lead to a more rational explanation of what Mr. Horger has referred to in connection with his tests on large and small size specimens. I would commend those who are interested in the theory and mechanism of fatigue to explore this in greater detail.

Mr. T. J. Dolan.[3]—This is a very interesting paper that brings out some very unusual phenomena which have not been well recognized in the past. It raises a number of questions that need a good deal of further work before they can be answered.

Can the authors tell briefly why the cold-drawn material behaves differently from the annealed material? It would seem that an explanation based on the phenomena of slip dislocation and accumulation of dislocations would apply equally as well to the annealed metal as to the cold-drawn material; the gradual growth of voids by accumulation of dislocations is a process that could be expected in both. Just what is the mechanism in the annealed material that raises its stress-strain curve, whereas, the cold-drawn material has its stress-strain curve lowered by the same migration of the various dislocations involved?

Mr. Frank A. McClintock.[4]—The authors suggested that further experiments are needed in order to determine whether or not the incidence of strain-softening is associated only with cyclic stresses in excess of the fatigue limit. If such experiments show that softening occurs only under stresses above the endurance limit, then Orowan's theory of fatigue[5] has not been disproved. For work-hardening was involved in this theory only to show how the endurance limit can be above the stress at which plastic flow occurs. If there were no work-softening below the endurance limit, and hence no plastic flow, then the observations could still be fitted by a model consisting of elements with a yield point followed by work-softening. Thus, these additional experiments would be an especially important addition to the interesting work reported by the authors.

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[1] Supervisor, Creep and Fatigue Laboratories, Bell Telephone Laboratories, Inc., New York, N. Y.

[2] J. N. Kenyon, "The Reverting of Hard-Drawn Copper to Soft Condition Under Variable Stress," *Proceedings*, Am. Soc. Testing Mats., Vol. 50, p. 1073 (1950).

[3] Head of Department of Theoretical and Applied Mechanics, University of Illinois, Urbana, Ill.

[4] Assistant Professor of Mechanical Engineering, Massachusetts Institute of Technology, Cambridge, Mass.

MR. J. M. LESSELLS.[6]—The paper is of considerable interest in the field of fatigue. While the hypothesis that a fatigue crack develops from extreme strain-hardening in certain microregions has not as yet been confirmed by experiment, the hypothesis seems plausible. In the paper, the authors discuss the softening effect of cyclic stress on cold-worked copper. Gough[7] has shown the opposite effect of a work-hardening effect on soft copper due to a cyclic stress.

Much has yet to be learned regarding the rôle of ductility in the fatigue problem and what is meant by ductility. It is of interest to note that fully heat-treated alloy steel which has high ductility as measured by the tension test shows no increase in fatigue strength due to understressing in fatigue; nevertheless, cast iron, which is regarded as a brittle material with negligible ductility, may show 25 per cent[8] increase in fatigue strength by understressing.

MR. L. F. COFFIN, JR.[9] (*by letter*).—The subject matter of this paper relates very closely to an investigation carried out at the Knolls Atomic Power Laboratory and reported recently.[10, 11] In that study the fatigue behavior of type 347 stainless steel was investigated both under constrained thermal cycling (to simulate thermal-stress fatigue failure) and constant temperature strain cycling. The cyclic strain levels employed in each case were sufficiently high to produce failure in 1000 to 100,000 cycles. The apparatus was such as to permit continuous measurement of the cyclic stress so that the progressive increase (strain-hardening) or decrease (strain-softening) in the height of the hysteresis loop could be observed while maintaining the width of the loop constant.

For annealed stainless steel, a gradual hardening occurs which, considering the marked strain-hardening tendency exhibited by this material in monotonic tension, is very slight. The increase is such that, when plotted against the logarithm of the number of strain cycles, a saturation is observed. The amount of strain-hardening increases by increasing the amplitude of the strain change, but saturation again occurs.

On the other hand, stainless steel test specimens cold-worked by prior torsion or tension exhibit a completely different behavior when thermally cycled under uniaxial constraint or when strain cycled at constant temperature. Here, with a constant strain change, a progressive decrease in stress change is observed with the number of cycles of strain. This strain-softening of the material is currently being studied in more detail, but the rate of softening appears to increase with the amount of prior strain and with strain change per cycle. Other tests have shown that the phenomenon is not due to thermal annealing of the material during the test, since similar effects are observed at room temperature.

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[5] E. Orowan, "Theory of Fatigue of Metals," *Proceedings*, Royal Society (London), Vol. 171-A, p. 79 (1939).

[6] President, Lessells and Associates, Inc., Boston, Mass.

[7] H. J. Gough, "Elastic Limits of Copper Under Cyclical Stress Variations," *Engineering*, Vol. 114, Sept. 8, 1922, p. 291.

[8] J. B. Kommers, "Understressing and Notch Sensitivity in Fatigue," *Engineering News Record*, Vol. 109, Sept. 22, 1932, p. 353.

[9] Research Associate, Knolls Atomic Power Laboratory, Schenectady, N. Y. (operated for the U. S. Atomic Energy Commission by the General Electric Co.).

[10] L. F. Coffin, Jr., "A Study of the Effects of Cyclic Thermal Stresses on a Ductile Metal," *Transactions*, Am. Soc. Mechanical Engrs., August, 1954, p. 931.

[11] L. F. Coffin, Jr., "The Problem of Thermal Stress Fatigue in Austenitic Steels at Elevated Temperatures," Symposium on Effect of Cyclic Heating and Stressing on Metals at Elevated Temperatures, Am. Soc. Testing Mats., p. 31 (1954). (Issued as separate publication *ASTM STP No. 165*.)

The strain-softening as discussed above and the softening by stress cycling reported by the authors are obviously very closely related, but certain differences do exist. One difference, of course, is in the method of observation, since the authors have observed the softening by subsequent compression testing of the fatigue specimens subjected to prior stress cycling, while in the writer's tests the softening is observed progressively. Thus, in one case, it is shown that the yield stress progressively decreases, while in the other case the shape of the flow stress curve is altered, so that at subsequent strains of some magnitude the stress is lowered by stress cycling. A second and less significant difference is in the methods of test, one being accomplished by stress cycling, the other by strain cycling. Under stress cycling the softening effect would result in an increased cyclic strain change, the result being, as pointed out by the authors, to reduce the fatigue strength below that which might exist if softening could have been prevented.

The writer has suggested[10] that the softening process may be due to the gradual decrease of high internal energy in the structure brought on by cold-work. Thus slip planes which are prevented in whole or in part from moving because of cross slip, or high back stresses produced at grain boundaries as a result of prior cold-work, now move more freely. The agitation supplied to the structure by cyclic strain is here thought to be the motivating factor in reducing these regions of high energy by permitting adjustments in the structure to lower energy level.

In view of the above described behavior and that described by the authors in their excellent paper, it is quite difficult to accept a mechanism for fatigue failure built around a strain-hardening hypothesis.

The writer concurs with the authors in that fatigue failure would more logically be a result of some process which under cyclic strain causes the nucleation of voids and the growth of these voids into cracks, rather than a failure resulting from excessive strain-hardening.

MESSRS. N. H. POLAKOWSKI AND A. PALCHOUDHURI (*authors' closure, by letter*).—The authors wish to thank the contributors to the discussion for their stimulating comments.

In reply to Mr. Gohn, a somewhat detailed reference to J. N. Kenyon's work[2] was made in a previous paper by one of the present authors.[12] Since heavily cold-worked copper shows occasionally self-annealing tendencies, it was important to demonstrate that "work-softening" may occur under conditions where self-annealing does not come into the picture.

It is gratifying to see that the views of physicists and engineers approach a stage when their respective explanations of the same phenomenon are reduced to matters of nomenclature rather than substance.

The authors feel that Mr. Dolan's questions cannot as yet be answered satisfactorily in terms of atom movements, dislocations, and the like. The physics of metals has not supplied so far a clear and convincing picture of the mechanism causing metals to harden during plastic flow,[13] and it would perhaps be premature to speculate on the ultimate origin of work-softening before the first named problem is solved. It is suggested, however, that a likely interpretation of the reported facts may be built up around the concepts of internal strain energy and the "generalized Bauschinger effect" put forward in a previous publication.[14]

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[12] N. H. Polakowski, "Restoration of Ductility of Cold-Worked Aluminum, Copper, and Low-Carbon Steel by Mechanical Treatment," *Proceedings*, Am. Soc. Testing Mats., Vol. 52, p. 1086 (1952).

Mr. McClintock's contention that the concept of progressive work-hardening was used in Orowan's theory merely to illustrate how the fatigue limit can be above the yield stress is not one that can be accepted, for it was essential that the peak of the zigzag diagram be above some limiting stress (for example, the true ultimate tensile strength) in order to explain final fracture under fatigue stresses in excess of the endurance limit. As the authors see it, the Orowan theory was designed, in effect, to provide a formal interpretation of the fatigue behavior of initially "soft" metals. Such materials invariably work-harden during cyclic stressing irrespective of whether the stress applied is below or above the endurance limit.

Mr. Lessells raised two important questions in his second paragraph. Since these are not directly related to the subject matter of the present paper, it would be impractical to discuss them at length at this juncture in spite of their intrinsic interest. It may be pointed out, nevertheless, that Sinclair[15] has shown that coaxing is essentially a result of strain aging. One can thus easily visualize how the ferritic matrix of cast iron with its low elastic limit may gradually work-harden during the fatigue test whilst being subject to spontaneous strain aging at the same time. The above does not apply to hardened-and-tempered steel which has a high elastic limit and is structurally stable under cyclic stresses which are close to but still below the endurance limit.

The authors were glad to have the comments of Mr. Coffin and they were particularly pleased by the basic agreement between his and their own results. This feature was quite conspicuous notwithstanding the differences in the experimental materials and techniques.

The idea of ascribing the work-softening process to a decrease of internal strain-energy is fruitful but not entirely new. It was employed in a paper published a few years ago[14] to account for a variety of phenomena closely related to the subject matters of both Mr. Coffin's and the present authors' papers. It was a little disappointing to find that no reference to this work was made by Mr. Coffin in either of his two papers.

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[13] A. H. Cottrell, "Dislocations and Plastic Flow in Crystals," p. 151, Clarendon Press, Oxford (1953).

[14] N. H. Polakowski, "Softening of Metals During Cold Working," *Journal of The Iron and Steel Institute*, Vol. 169, p. 337 (1951).

[15] G. M. Sinclair, "An Investigation of the Coaxing Effect in the Fatigue of Metals," *Proceedings*, Am. Soc. Testing Mats., Vol. 52 p. 743 (1952).

METALLOGRAPHIC ASPECTS OF FATIGUE BEHAVIOR OF ALUMINUM*

By M. S. Hunter[1] and W. G. Fricke, Jr.[1]

Synopsis

Metallographic methods are described for following the formation and progress of fatigue cracks in aluminum and aluminum alloys from very early in the fatigue life to final, complete failure. When an aluminum specimen is subjected to fatigue action, its surface appearance undergoes a continuous sequence of submicroscopic and microscopic changes. These progressive changes include the development of submicroscopic slip bands within individual grains, the formation of extremely fine cracks within individual grains, the joining of cracks across grain boundaries to form major cracks, and the extension of these major cracks until sudden, complete, tensile failure of the material occurs. Points denoting the cycles required to produce these several stages of progressive change at various stress levels fall on smooth curves which bear a relationship to each other and to the familiar *S-N* curve denoting final failure. The specific relationship of these families of curves differs with the alloy and temper of the material under test.

The fact that metals and alloys subjected to repeated loading will fail at a stress level well below the static strength of the material has been of concern to those responsible for the performance of metals in service. Much time and energy has been expended in obtaining a better understanding of the behavior of metals subjected to cyclic stressing and in establishing the limits of stress that may be applied repeatedly to structural elements without danger of fatigue failure. This paper describes several metallographic methods used to follow the extremely minute changes that result from repeated stressing. It also illustrates some of the changes caused by fatigue action in certain aluminum alloys and demonstrates that there is a relationship between these changes in structure and the ultimate behavior of the material.

In the past, a dual approach has been used to attack the fatigue problem. Extensive testing has revealed the fatigue characteristics of a wide variety of commercial alloys and has established the life expectancy of these alloys under various stress conditions (**1**).[2] This work defines the conditions under which these alloys may be used commercially and forms the basis for the design of structures subjected to cyclic stressing. The other approach has been of a more fundamental nature and has been aimed at obtaining a better understanding of the behavior of metals under fatigue action. This fundamental work has furnished a reasonable explanation of fatigue behavior and has shown that fatigue failure does not occur suddenly but is actually the culmination of a series of events (2–11).

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13–18, 1954.

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[2] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 732.

METHODS OF INVESTIGATION

Inasmuch as the initial changes in surface appearance resulting from fatigue action are apparently of extremely small magnitude, methods capable of revealing minute changes in surface appearance were selected. It was possible to show changes at an early stage, to detect the first minute microcracks, and to follow the enlargement and progress of these cracks through to the final, complete failure of the specimen. This was accomplished by using polished fatigue specimens, a simple plastic replica technique, and optical and electron microscope examinations.

In the preparation of specimens for this investigation, chemical polishing was employed. This treatment was advantageous because it produced over the entire surface of the fatigue specimen a smooth, highly polished surface which permitted extremely small changes to be seen and recognized. It eliminated the worked surface layer that is characteristic of surfaces polished mechanically and that might have some effect on fatigue behavior. In addition, the particular chemical polishing treatment revealed many of the microstructural features of the aluminum alloys so that it was possible to establish the relationship between the structure of these alloys and the starting point and path of fatigue cracks.

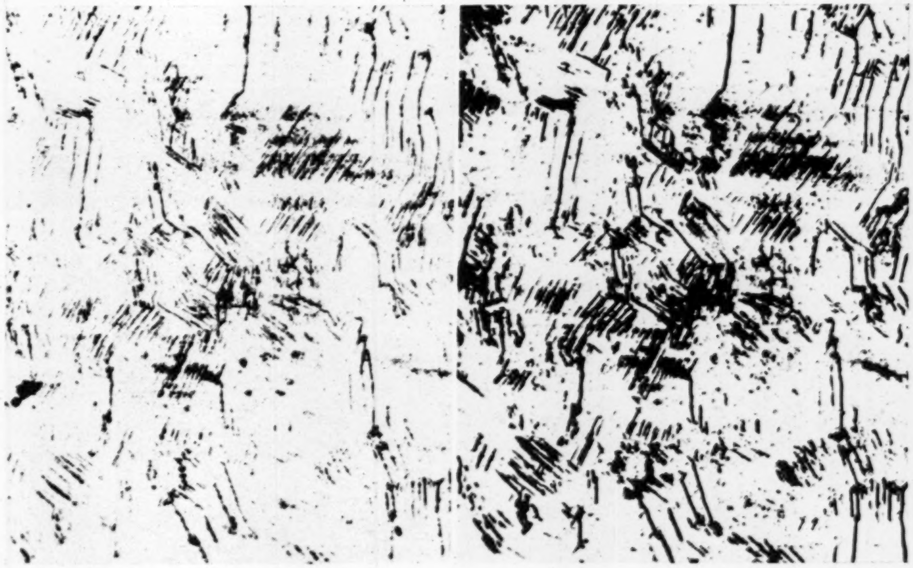
Plastic replicas were used to examine and record the changes in surface appearance that occurred as a result of fatigue action. These replicas were made by putting a drop of plastic dissolved in a solvent on the specimen and smoothing a piece of solid plastic strip onto the liquid. The two bond together, and a faithful reproduction of the surface of the specimen is obtained. This technique has been used extensively in metallographic work and is capable of revealing extremely fine detail with exceptional clarity. The plastic replicas are examined by transmitted light and may be used at any magnification of which the light microscope is capable. The appearance of the surface of the specimen as seen with the replica is the same as if the specimen itself were being examined by vertical illumination. A series of replicas of this type taken during the course of a fatigue test forms a permanent record of the fatigue life of the specimen.

When examinations at magnifications higher than those obtainable with the light microscope are desired, further replicas for electron microscopic examination may be made from the plastic replicas by the "triple replica" method (12). In this method, a layer of aluminum is evaporated onto the plastic replica, and an aluminum oxide replica is made from this evaporated aluminum layer. Replicas produced by this method record the fine surface detail of the specimen and, in effect, permit examination of the surface of the specimen at the high magnifications obtainable with the electron microscope.

Another method employed was the use of a 20 per cent by weight solution of sodium hydroxide at room temperature for differentiating between microcracks and irregularities of surface contour developed by slip. The nature of this etching treatment is such that it exaggerates greatly any small metal discontinuities. Thus, if a microcrack is present it will be enlarged by the etching treatment and will be more readily visible (Fig. 1). With a surface irregularity that does not involve a metal separation, however (such as the case of a surface offset produced by slip), exaggeration does not occur and there is little change in surface appearance.

Use was also made of the dye-penetrant inspection method, which has received rather wide acceptance in industry as a method for detecting certain cracks and other flaws that are otherwise invisible to the eye. In this method, a low surface tension liquid containing a dye is applied to a surface and penetrates any small discontinuities. After the excess penetrant is removed from the surface and a white, powdery, absorbent coating is applied, dye solution remaining in the discontinuities bleeds out and colors the white coating. The colored spots or lines on the white background establish the location of the discontinuities. The principal limitation of the dye-penetrant method lies in the fact that a discontinuity will be detected only if its geometry is such that it can accept and retain enough dye to color the white coating. Thus, only those discontinuities having sufficient width in relation to the surface tension of the penetrant and an appreciable depth-to-width ratio will be detected by this method.

In certain phases of this work, it was desirable to obtain a quantitative value for the amount of surface deformation on a specimen. The method used, adapted from a method described by Smith (**13**), consisted of projecting a randomly oriented grid onto the microstructure of the surface of a specimen and counting the number of intersections between the grid and the deformation lines. The amount of deformation in terms of the length of deformation lines per area of field was given by:



(*a*) Before sodium hydroxide etching. (*b*) After sodium hydroxide etching.

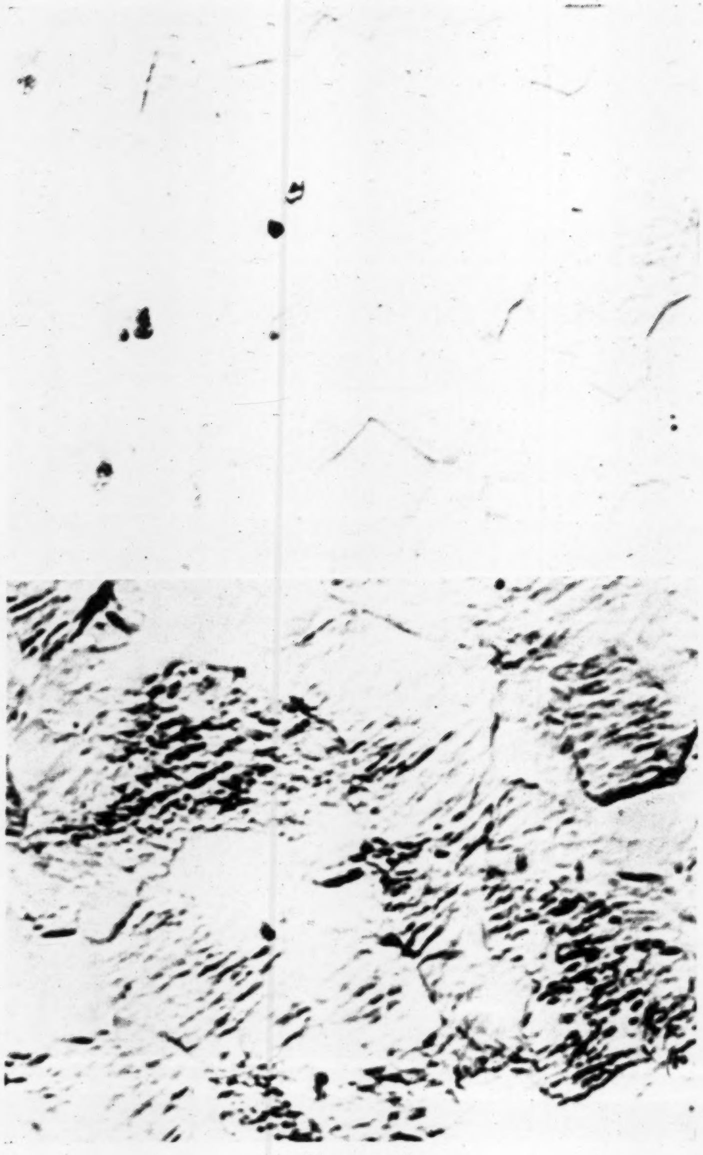
FIG. 1.—Crack Detection on Alclad 24S-T3 Sheet with 20 per cent Caustic Solution (× 100).

$$\frac{L}{A} = \frac{\pi I}{2l} \qquad (1)$$

where:

L = total length of deformation lines,
A = area of field,
I = number of intercepts, and
l = total line length of grid.

(*a*) Early slip.



(*b*) Slip saturation.

FIG. 2.—Stages of Progressive Change in the Fatigue Life of DD1S-0 Sheet (× 500).

MATERIALS AND TESTING METHOD

The alloys used in this investigation were Alclad 24S-T3, DD1S-0 (the coating material on Alclad 24S sheet), 24S-T3, and 75S-T6 alloys in the form of 0.064-in. thick sheet, and 75S-T6 alloy in the form of $1\frac{1}{4}$-in. rolled and drawn rod. The sheet materials were tested in alternate flexure with constant deflection, whereas the rod was tested as smooth, rotating-beam specimens in R. R. Moore-type machines.

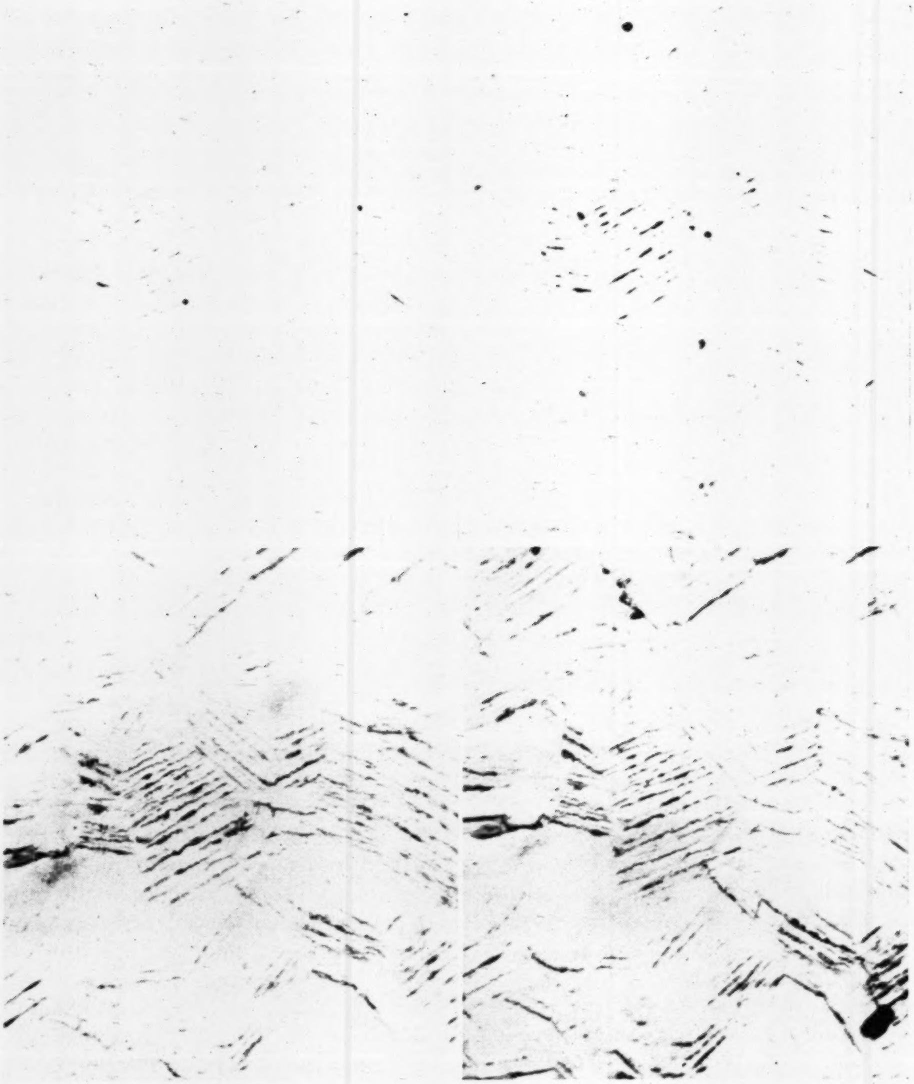
PROGRESSIVE CHANGES RESULTING FROM FATIGUE ACTION

Application of the various methods of examination has revealed the sequence of events that takes place during the life of fatigue specimens of aluminum and aluminum alloys. The changes that occur as a result of fatigue action are actually continuous, but, for convenience, they may be divided into a number of stages. The time in the fatigue life at which these stages are reached and the duration of the separate stages are functions of the stress level and the particular material under test. Consequently, all stages of change may not be observed with all materials or at all stress levels. Further, the frequency of examinations and the sensitivity of the examination methods will have a bearing on whether or not a particular stage is detected and the time in the fatigue life at which it is apparent.

From observations of the changes occurring on the surface of specimens of various types of aluminum alloys, a composite picture of the changes that take place during the fatigue life is apparent. The first change observed is deformation resulting from slip. Under the light microscope, this deformation appears as individual lines within various grains (Figs. 2(*a*) and 3(*a*)). The electron microscope, however, shows that these lines are actually groups of roughly parallel slip deformations (Fig. 4). These bands of slip extend transgranularly with respect to the subgrain structure of the material and apparently bear no relation to the direction of the subgrain pattern.

As cyclic stressing continues, deformation from slip becomes more and more pronounced, both qualitatively as indicated by visual examination and quantitatively as determined by Eq 1. During this stage, the characteristics of the material and the sensitivity of the inspection method determine at what point the deformation is evident. With further fatigue action, a point which may be called "slip saturation" is reached (Fig. 2(*b*)). This point represents a pronounced change in the rate of increase of deformation with continued fatigue action. Up to this point, the amount of deformation has been increasing rapidly, whereas beyond this point the rate of increase is much slower.

Still further fatigue action soon brings the material to the stages involving cracking. Initially, the cracks are very fine (Fig. 3(*b*)) and can be observed only with the more sensitive methods of examination. From light microscopic examination, it appears that the crack forms along one of the slip lines already present and, therefore, may be the result of failure on an overworked slip plane. The electron microscope, however, shows that the crack forms parallel to and along the edge of a group of slip deformation lines (Fig. 4). This could constitute failure on an overworked slip plane, but the fact that the cracks tend to form at the edge of the deformation bands and the step-like configuration of the deformation lines suggest another possible fatigue mechanism. It appears possible that, as successive slip lines of a group develop, localized stress concentration is produced by each slip opera-



(*a*) Early slip.

(*b*) Initial cracking.

(*c*) Extensive cracking within grains.

(*d*) Crack joining.

FIG. 3.—Stages of Progressive Change in the Fatigue Life of Alclad 24S-T3 Sheet (× 250).

tion, with the result that the slip movement of the next slip operation is greater. This would develop a series of steps, each higher than its immediate predecessor. Continuation of this process would increase the localized stress concentration and increase the extent of the next slip movement until finally the movement would be greater than the material could withstand, and a crack would result.

Still further fatigue action enlarges the initial cracks and develops additional smaller ones until, with certain materials, much of the surface is covered with fine cracks (Fig. 3(*c*)). Up to this point, the fine cracks—and the slip lines which have preceded them—are confined to individual grains and appear as families of parallel markings within these grains. The orientation and severity of these markings are apparently related to the crystallographic orientation of the grains and their relation to the stressing direction.

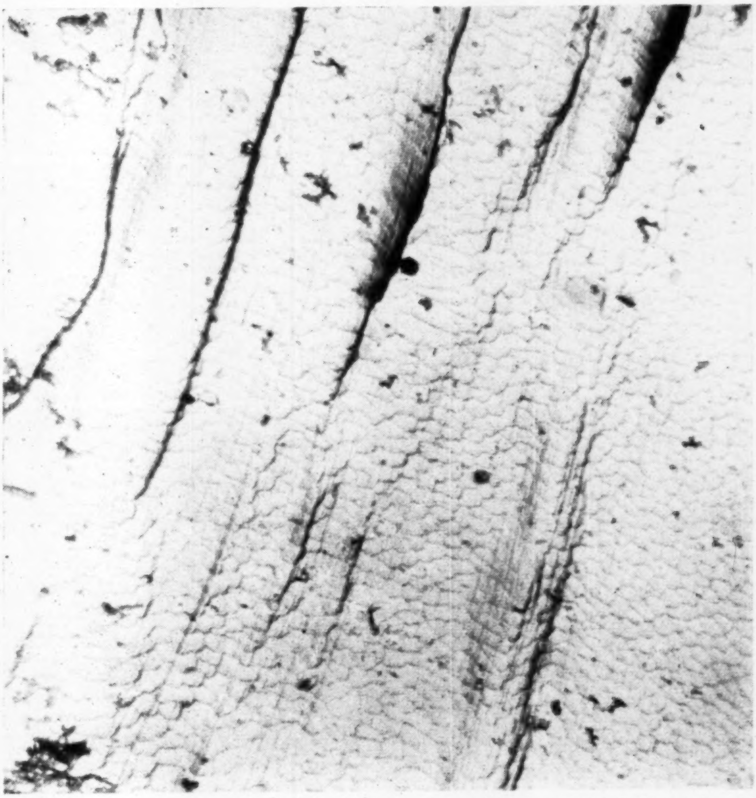


FIG. 4.—Electron Micrograph of Slip Bands on Surface of Alclad 24S-T3 Sheet (× 15,000).

Cracks have formed along the edges of the bands in the upper part of the picture. General structure pattern is the subgrain structure of the material. Oxide film replica.

After the formation and development of cracks within individual grains, the remaining portion of the fatigue life is occupied by crack extension. This process involves principally the joining and

(*a*) Main crack. (*b*) Fine cracks on reverse side. (*c*) Cross-section.

FIG. 5.—Fine Cracks on Reverse Side of 75S-T6 Sheet Formed in Advance of Deepening Fatigue Crack (× 100). (Reduced 1/5 in reproduction.)

deepening of existing cracks, although some additional cracking may develop as a result of stress redistribution as large cracks propagate. If the surface of the specimen is generally cracked, crack extension consists of the joining of cracks within individual grains at their mutual boundaries (Fig. 3(*d*)). Once a crack through several grains has formed in this manner, this crack will progress, joining up wherever possible with existing cracks within individual grains. At the same time, the crack is extending in depth and will continue to do so until the remaining cross-sectional area of the specimen can no longer support the load, and sudden tensile failure occurs.

In the case of strong aluminum alloys, which do not exhibit general cracking of the surface, crack extension consists principally of the progression of existing cracks across and through the material. It is probable, however, that the process of crack joining described above is actually taking place, but that the cracks ahead of the main crack are not visible by ordinary methods of examination.

In connection with the crack extension phase, two other interesting features have been observed. One of these has been observed in the testing of sheet materials and probably applies to any relatively thin section. It was noted that as a relatively large crack extended through the sheet specimen, a multitude of fine cracks developed on the reverse side of the specimen in advance of the crack (Fig. 5). This is apparently the result of stress redistribution brought about by the formation of the crack and constitutes evidence that a high-stress "front" is operative ahead of the crack.

FIG. 6.—Fine Cracks Formed Ahead of Main Fatigue Crack on Surface of 24S-T3 Sheet (× 100).

Another indication of this highly stressed region that precedes an advancing crack is the behavior of the surface of the specimen ahead of such a crack. As a crack approaches a given area, the material frequently undergoes very rapidly the series of changes that would otherwise occur in a much longer period. Also, numerous fine cracks are frequently formed even in a material that does not usually exhibit general cracking (Fig. 6).

DETECTION AND SIGNIFICANCE OF PROGRESSIVE CHANGES

The various methods described are capable of detecting and following the changes resulting from fatigue action from very early slip to final complete failure. Electron microscopy is best suited for observing exceptionally minute changes that are of particular interest in investigations of the theoretical aspects of fatigue and is not readily adaptable to investigation of the more advanced stages of change. The plastic replica method, in conjunction with light microscopy, will detect early changes in surface appearance. It is more useful for observing the later stages of change, however, particularly those associated with the beginning of structural damage. Dye-penetrant inspection is a very simple and convenient means of revealing cracks, but it will reveal only those cracks that have reached a relatively advanced stage of development. This method appears to be practical for inspecting members subjected to fatigue action, however, and should give adequate warning of impending failure.

Regarding the significance of the progressive changes occurring during the fatigue life, the fact is evident that initial changes will have no significant effect on the strength of a part or structure, whereas later changes may have a disastrous effect. Any of the changes involving only slip do not necessarily indicate that the material has sustained damage, because no actual metal separation has occurred. Actually, this slip may be beneficial because of the slip hardening involved. Observation of these changes is useful, however, because they indicate that progressive deformation is occurring and that changes involving damage will probably occur if fatigue action continues.

The significance of the stages involving cracking of a part will depend on many factors, including the particular use of the part, the thickness of the section, and the conditions under which it is operating. The first crack seen on the surface by microscopic examination of a plastic replica would probably not constitute significant damage because it will generally be less than 0.0001 in. in depth. On the other hand, when a crack is first detected by dye-penetrant methods, it will have penetrated to a much greater depth and may be highly significant as far as performance is concerned, particularly if it occurs in a thin section.

PROGRESSIVE CHANGES IN ALUMINUM ALLOYS

The various stages of progressive change that may be seen in several aluminum alloys have been determined. It has been found that with materials of relatively low strength most of the changes observed prior to failure consist of the slip stages with but little evidence of the stages involving cracking. On the other hand, with aluminum alloys of relatively high strength, the earlier stages of change were difficult or impossible to detect. Most of the change observed during the fatigue life consists of cracking and crack extension. It is believed, however, that all stages actually occur in all materials.

In the case of DD1S-0, which is unalloyed aluminum of 99.5 per cent purity and is a relatively soft material, the various slip stages were evident (Fig. 2), but very little cracking was apparent before final failure. Slip was observed very early in the test and increased in intensity and amount as the test progressed. The total deformation, as determined by Eq 1, increased exponentially with the number of cycles in accordance with the equation:

$$\frac{L}{A} = cN^{m} \quad \text{..............} (2)$$

where N is the number of cycles, and c and m are constants for any given stress level but are actually functions of the stress. Thus, the total deformation at any particular period is a function of the stress. This increase in surface deformation continued over a considerable portion of the fatigue life until the slip saturation point was reached. First cracking could not be established with certainty because of the extensive surface roughening developed by slip. After the slip saturation point, a small amount of additional deformation occurred, some large cracks formed and, finally, the specimen failed.

With Alclad 24S-T3 sheet, the thin layer of DD1S-0 which is metallurgically bonded to the 24S alloy core is supported by the core and cannot fail completely until the core itself fails. This supporting action brings about some change in the behavior of DD1S-0 in that the evidence of slip tends to be suppressed, although slip as well as the succeeding cracking stages can be observed (Fig. 3). Early in the fatigue life, slip of the alclad coating within individual grains is observed as it is in the case of the coating alloy alone. This slip never becomes very pronounced, however, because the strong alloy core prevents extensive movement. Later in the test, cracks form along existing slip lines within individual grains and, as

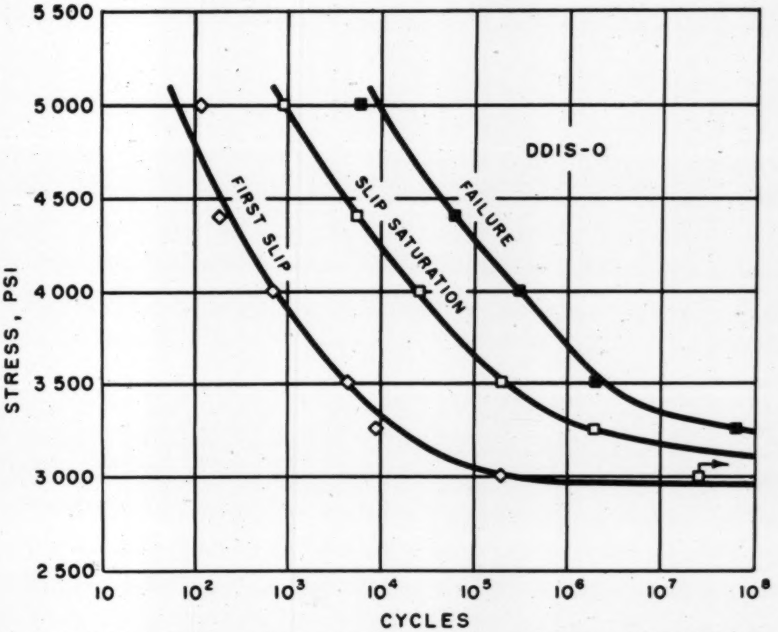


FIG. 7.—Relation Between Stages of Progressive Change Observed on DD1S-0 Sheet.

the test continues, extensive cracking within these grains occurs. When many of the grains of the coating alloy contain numerous groups of parallel cracks, crack joining begins, after which practically no new cracks develop. As the larger cracks form and extend, they do so almost entirely by joining with existing cracks within grains that lie in their path. Eventually, after numerous relatively long cracks have formed in the coating, the specimen fails.

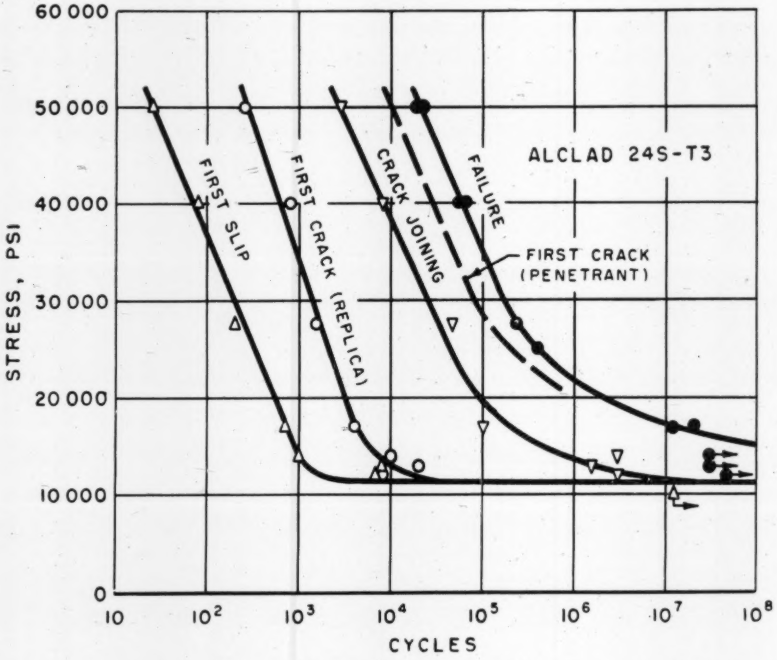


FIG. 8.—Relation Between Stages of Progressive Change Observed on Alclad 24S-T3 Sheet.

It has been found that not only does the strong alloy core influence the behavior of the DD1S-0 coating but also that the behavior of the coating reflects changes that are taking place in the core. During the slip and early cracking stages through which the coating progresses, no visible change in the core can be observed. The only changes evident in cross-section are the cracks formed within the coating layer and the extension of these cracks inward to the coating-core interface. Thus, prior to the crack-joining stage observed on the surface of the coating, the core—and consequently the product as a whole—has sustained no structural damage in spite of the widespread cracking apparent in the coating. The start of the stage of crack joining in the coating is a landmark in the life of the core, however, because it is at about this point that cracking of the core begins. As crack joining and crack extension occur in the coating, cracks form and progress in the core until the remaining section can no longer support the stress, and the specimen fails.

The changes observed during the fatigue life of 24S-T3 and 75S-T6 alloys are similar and are probably typical of high-strength aluminum alloys in general. Because of their strength and the relatively small amount of slip that can occur without cracking, the slip stages are seldom seen with these alloys. Consequently, the first stage of progressive change generally observed is cracking. Also, with these alloys, there is less tendency for general crack formation and, as a result, most of the period between formation of the first crack and ultimate failure is occupied by crack extension. This process generally appears as a simple lengthening and deepening of existing cracks, although the process of crack joining may actually be taking place on a submicroscopic scale.

In the course of this investigation, observations were made of the effect of constituent particles in so far as they influence the starting point and progression of fatigue cracks. It was found that the constituent particle *per se* does not act as a focal point for the start of a fatigue crack. Furthermore, an advancing crack does not follow a path from one such particle to another. In many cases, cracks actually detour around constituent particles. This behavior is not surprising because, in contrast to inclusions, the constituents in aluminum alloys are an integral part of the alloys and are coherent with the solid solution matrix. From theoretical considerations, the hard constituent particles might be expected to give support to the surrounding matrix. Further, the matrix adjacent to a constituent particle will have a slightly higher amount of the alloying elements in solid solution and, consequently, will be stronger and more able to resist the slip that precedes cracking.

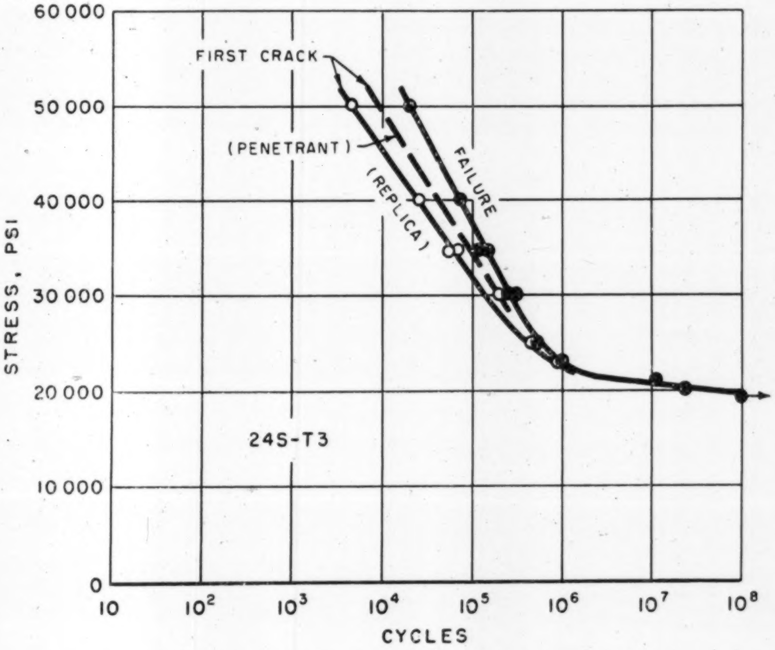


FIG. 9.—Relation Between First Cracking and Failure of 24S-T3 Sheet.

An entirely different situation exists if voids are associated with constituent particles, as in the case of gross constituent segregation, or if notches are created by chipping out parts of a large constituent particle during machining of a part or preparation of a specimen. If voids or notches are present on the surface, they will frequently act as focal points for the start of fatigue cracks. Also, an advancing crack will generally go through such notches or voids as it progresses. In such cases, however, it is the notches or voids rather than the constituent particles that are the controlling factors.

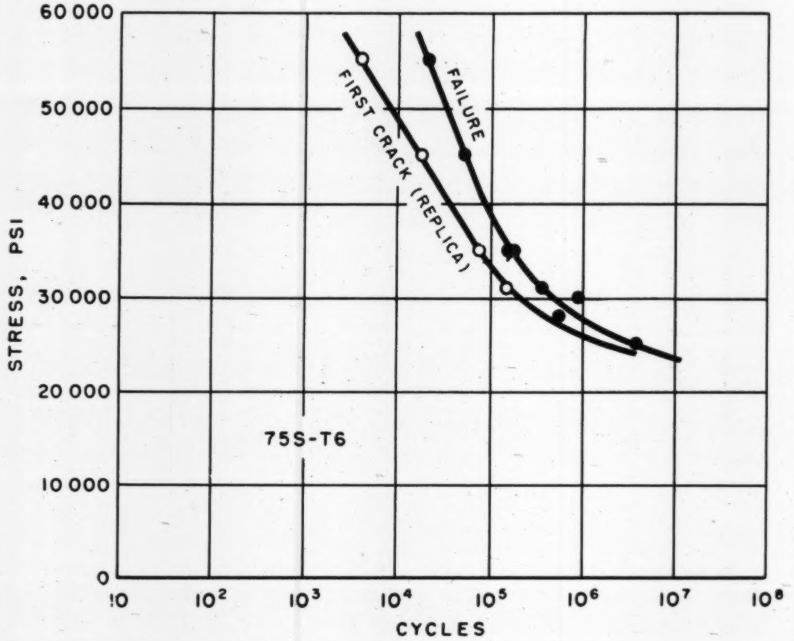


FIG. 10.—Relation Between First Cracking and Failure of 75S-T6 Rod.

CURVES OF PROGRESSIVE CHANGE

If the number of cycles required to reach each of the several stages of change at various stress levels is plotted, certain definite relationships are evident. It is found that the points for each of the stages fall on relatively smooth curves, that the various curves bear a relationship to each other, and that they also bear a relationship to the familiar *S-N* curve denoting failure. Curves denoting the first appearance of the various stages of progressive change in the aluminum alloys tested are shown by Figs. 7 to 11. When these relationships are considered in greater detail, it is apparent that the curves become asymptotic to the failure curve at the endurance limit, or become horizontal and parallel to this curve at a stress level slightly below the endurance limit as it is usually determined. This lower value probably represents an "ultimate endurance limit" or one that would be found at an infinite number of cycles.

It is evident that the relationship between the curves of progressive change and the failure curve are different for different materials. With the soft material DD1S-0, either alone (Fig. 7) or as the coating on the Alclad 24S-T3 sheet (Fig. 8), the curves are roughly parallel except at low stress levels, where they turn rather suddenly as they approach the endurance limit. In the case of the strong alloys, 24S-T3 and 75S-T6 (Figs. 9 and 10), the curves are more widely separated at high stress levels and gradually converge as they approach lower stress levels. In actual number of cycles of remaining life, however, the life expectancy is greater at lower stress levels.

Comparison of the curves of progressive change for DD1S-0 alone and as a coating on Alclad 24S-T3 sheet reveals another interesting relationship and illustrates the supporting effect of the core on the coating of the alclad product. If the curves for these two materials are plotted together on the basis of the calculated stress on the DD1S-0 (Fig. 11), it is indicated that the curves for this material as an alclad coating represent extrapolations of the DD1S-0 curves to higher stress levels. Thus, slip saturation in the DD1S-0 alone may represent the point of first cracking which is generally masked by the extensive surface roughening resulting from slip. Further, the crack-joining stage observed in the alclad coating apparently represents failure of the coating material, although complete failure cannot occur because the coating is held in place by the core. In addition, the divergence at low stress levels between the curves for the alclad coating and

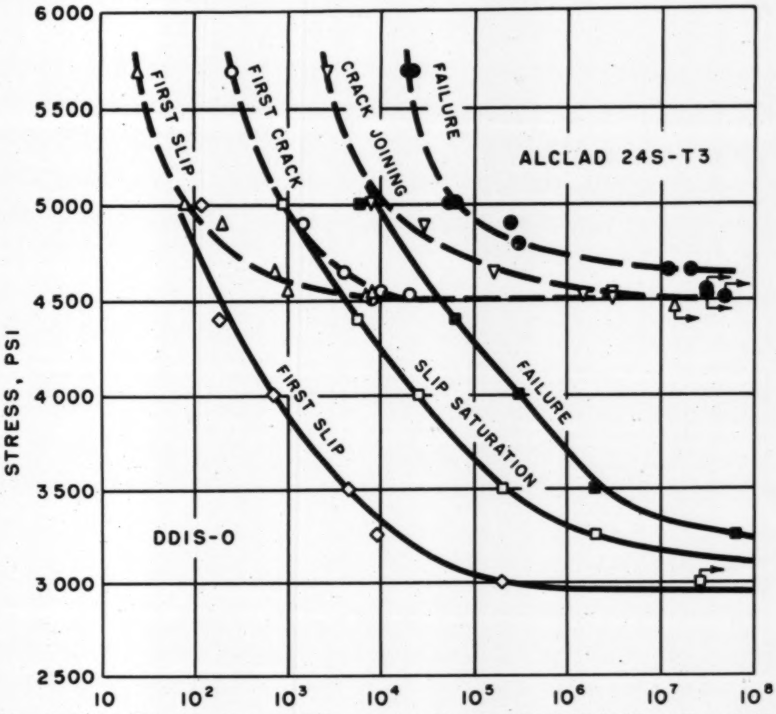


FIG. 11.—Relation Between Curves of Progressive Change of DD1S-0 When Tested Alone and as the Coating on Alclad 24S-T3 Sheet.

the projected curves for the DD1S-0 alone represent the extent to which the 24S alloy core affects the fatigue behavior of the coating.

CONCLUSION

Application of the metallographic techniques described has shown that a sequence of submicroscopic and microscopic changes occurs during the fatigue life of aluminum alloys and that there is a relationship between the number of cycles causing these minute changes and that required for complete failure. Further work with methods of this type should be extremely helpful in the evolution of a better understanding of the fundamental aspects of fatigue behavior, in the testing of structural materials, and in assisting those concerned with the design and maintenance of structures subjected to fatigue action in service.

Acknowledgment:

The authors wish to express their appreciation to E. H. Dix, Jr., R. L. Templin and F. Keller, under whose direction this investigation was conducted, to various members of the Mechanical Testing Division of these Laboratories who conducted the fatigue tests, and to D. L. Robinson who made the electron microscope examinations.

REFERENCES

(1) R. L. Templin, "Fatigue of Aluminum," Gillett Memorial Lecture, see p. 641, this publication.

(2) G. B. Upton, "The Structure and Properties of the More Common Materials of Construction," John Wiley and Sons, Inc., New York, N. Y., 1st Ed., p. 112 (1916).

(3) H. F. Moore and T. Ver, "A Study of Slip Lines, Strain Lines, and Cracks in Metals Under Repeated Stress," *Bulletin No. 208*, Engineering Experiment Station, University of Illinois, June 3, 1930.

(4) H. J. Gough, "Crystalline Structure in Relation to Failure of Metals Especially by Fatigue," *Proceedings*, Am. Soc. Testing Mats., Vol. 33, Part II, p. 3 (1933).

(5) A. K. Head, "Mechanism of Fatigue of Metals," *Journal of Mechanics and Physics of Solids*, Vol. 1, p. 134 (1953).

(6) P. J. E. Forsyth, "Some Metallographic Observations on Fatigue of Metals," *Journal*, Inst. Metals (British), Vol. 80, pp. 181–186 (1951).

(7) W. J. Craig, "An Electron Micrograph Study of the Development of Fatigue Failures," *Proceedings*, Am. Soc. Testing Mats., Vol. 52, p. 877 (1952).

(8) F. P. Bullens, A. K. Head, and W. A. Wood, "Structural Changes During the Fatigue of Metals," *Proceedings*, Royal Soc., Series A, Vol. 216, pp. 332–343 (1953).

(9) P. L. Teed, "Fatigue of Aircraft Materials with Special Reference to Microstructure," *Journal*, Royal Aeronautical Soc., Vol. 56, pp. 427–437 (1952); *Aeronautical Engineering Review*, Vol. 11, p. 111 (1952).

(10) F. A. McClintock, "Fatigue Tests of Single Crystals of Ingot Iron," *Proceedings*, 1st U. S. National Congress on Applied Mechanics, Am. Soc. Mechanical Engrs., pp. 653–659 (1952).

(11) W. J. Love, "Structural Changes in Ingot Iron Caused by Plastic and Repeated Stressing," *Technical Report No. 33*, Office of Naval Research, Project NR-031-005, University of Illinois, November, 1952.

(12) M. S. Hunter and F. Keller, "Techniques Used in Electron Microscopy of Aluminum Alloys," Symposium on Techniques for Electron Metallography, Am. Soc. Testing Mats., p. 3 (1954). (Issued as separate publication *ASTM STP No. 155*.)

(13) C. S. Smith, "Microstructure," *Transactions*, Am. Soc. Metals, Vol. 45, p. 557 (1953).

DISCUSSION

Mr. B. J. Lazan.[1]—The techniques described and the results presented should contribute substantially towards better understanding of the fundamental aspects of fatigue. I therefore hope that the authors will continue this fine work and elaborate on the excellent start they have made.

At the University of Minnesota we are approaching this problem of fatigue-initiated changes from another viewpoint. Damping-energy dissipation and dynamic modulus of elasticity are measured continuously during the course of a fatigue test. The changes observed in damping and dynamic modulus parallel somewhat those observed metallographically by the authors and are therefore briefly discussed below for aluminum alloy 24S-T4.

The changes in total damping energy dissipated by a specimen during rotating-beam fatigue tests at several constant stress amplitudes are shown in the accompanying Fig. 12. Observe that at low stress amplitudes, say below 26,000 psi, damping is independent of number of stress cycles, whereas at high stress amplitude it changes significantly during the course of the fatigue test. These damping data are replotted on a damping *versus* stress basis in Fig. 13, specific damping being used in this figure to place the curves on a more fundamental basis.[2] The square dot has been labeled the "cyclic stress sensitivity limit" to indicate the stress below which the damping of the material does not change under sustained cyclic stress. Above this limit the family of curves shown is required to specify damping since stress history becomes an important variable. This sensitivity limit occurs at approximately 89 per cent of the fatigue strength at 2 × 10^7 cycles for this material.

The change in damping with number of stress cycles discussed above may be related to the horizontal spread between the first slip, first crack, and crack-joining points discussed by the authors, particularly in the finite life region. Similarly, the vertical spread at 2 × 10^7 cycles in the authors' Figs. 7, 8, 10, and 11 may be related to the observation made in damping studies[2] that the cyclic stress sensitivity limit is generally lower than the fatigue strength at 2 × 10^7 cycles.

The damping behavior and location of the cyclic stress sensitivity limit for other materials has been discussed.[2, 3] At Minnesota various methods have been tried to determine the "first evidence of crack" during a fatigue test and to associate this with damping *versus* number of stress cycle patterns. First of all, one is struck by the remarkably large number of small fatigue cracks which frequently appear in a specimen. Second, some fatigue cracks sometimes appear

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[1] Professor of Materials Engineering, University of Minnesota, Minneapolis, Minn.

[2] B. J. Lazan, "Fatigue Failure Under Resonant Vibration Conditions," Wright Air Development Center Technical Report 54-20, March, 1954.

[3] See p. 895 this publication.

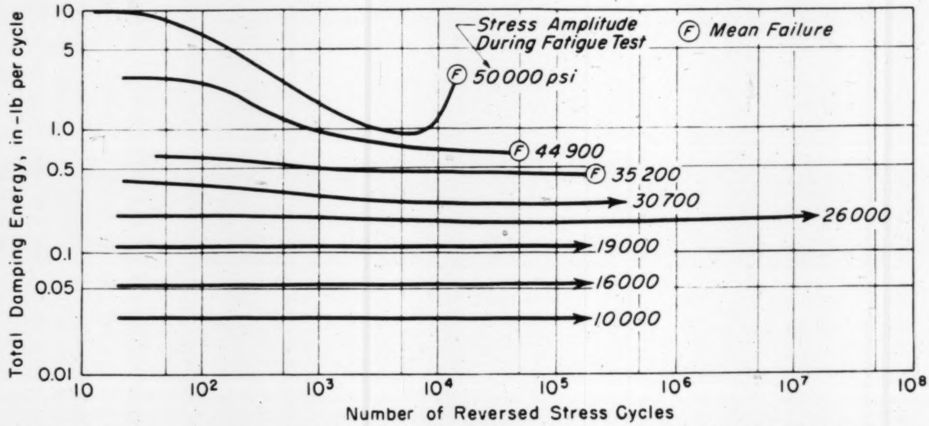

FIG. 12.—Change in Damping Energy Dissipated by 24S-T4 Aluminum Alloy Fatigue Specimens During Sustained Cyclic Stress of Various Amplitudes.

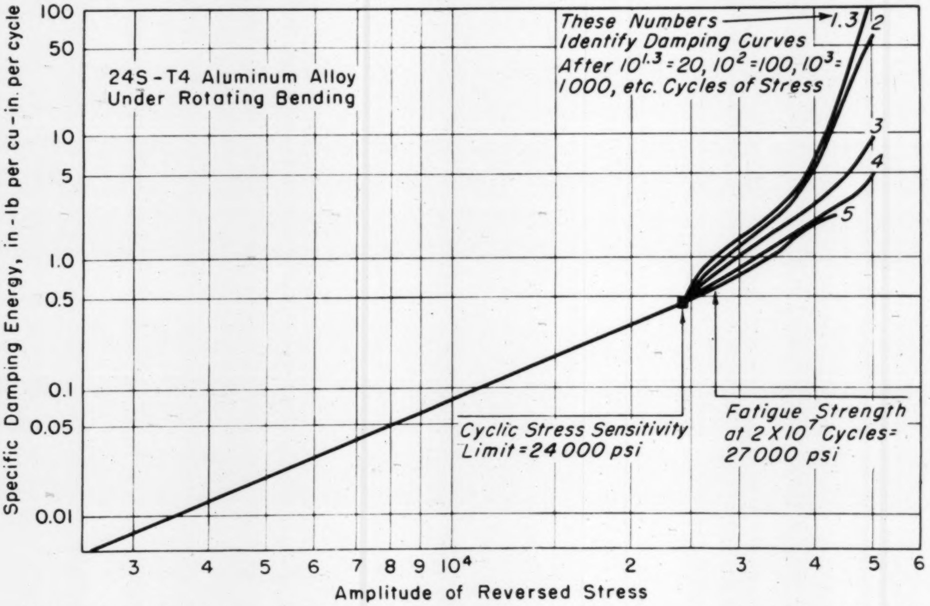

FIG. 13.—Effect of Stress Amplitude and Stress History on the Damping Properties of 24S-T4 Aluminum Alloy.

to stop growing during sustained cyclic stress. I would appreciate comments by the authors on their observations regarding the rate of fatigue crack propagation and local stoppage in propagation.

MR. J. T. DOLAN.[4]—The observation of the early stages of the initiation of slip recalls to mind a doctor's thesis at the University of Illinois by W. J. Love[5] which I think confirms many of the authors' finding. In one instance Mr. Love attempted to measure the percentage of the area of the extreme fibers of a flexural specimen in which he could observe slip. A plot of the percentage of the area with slip *versus* the logarithm of the number of stress cycles appeared to be a fairly straight-line relationship. This I think confirms the author's Eq 2 in which the exponent represents the slope of the line in Mr. Love's observations.

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[4] Head of the Department of Theoretical and Applied Mechanics, University of Illinois, Urbana, Ill.

[5] W. J. Love, "Structural Changes in Ingot Iron Caused by Prior Plastic Deformation and Repeated Stressing," Ph.D. Thesis, Department of Theoretical and Applied Mechanics, University of Illinois, Urbana, Ill. (1952).

Love found it difficult to detect the initiation of slip in the early stages with the light microscope; it would seem that the ability to locate cracks or slip in the very early stages is limited by the resolution of the microscope. In his observations as well as in the authors', no slip was detected within the first few thousand cycles. I am wondering if this is sufficient evidence that there was no slip or whether it occurred but could not be detected with the available techniques. I would like to ask specifically if the authors used the electron microscope in the early stages to search for evidence of slip within the first few hundred or few thousand cycles? Does the electron microscope give an earlier indication of slip than the light microscope?

Love also used the electron microscope with a replica technique and detected cracks in early stages of fatigue stressing. In one instance he found evidence of definite cracking in ingot iron at only 0.1 per cent of the nominal life to fracture of the specimen. This was somewhat earlier than those observed in the present paper but is further confirmatory evidence of permanent damage developed during early stages of repeated stressing.

MESSRS. M. S. HUNTER AND W. G. FRICKE, JR. (*authors' closure*).—It was hoped that the presentation of this paper would evoke comments and discussion and perhaps would stimulate other investigations along similar lines. It is gratifying to see part at least of the wish fulfilled.

We also, in addition to Mr. Lazan, have speculated as to whether changes in damping capacity might not be related to microstructural changes within the material. One reason for suspecting a correlation originates in published data of Mr. Lazan.[6] Figure 18 of his paper shows changes in damping capacity during fatigue tests of a mild steel at several stress levels. The curves are noted as deviating from linearity on the double logarithmic plot at four points for each stress level. If these points are replotted on the *S-N* curve they fall on smooth curves resembling our curves of progressive change of microstructure. For this material the plotted curves are roughly parallel to the failure curve.

The question of rate of crack propagation is an interesting though complex one. Several factors can operate to stop the advancement of a very small crack. One factor is almost certainly the orientation of grains in advance of the crack. While small, a crack lies on a definite crystallographic plane and may progress into an adjoining grain of similar orientation with little difficulty. If the orientation of grains is too dissimilar, the feeble stress magnification of the small crack may be insufficient to overcome the local "strength" of material and it will not propagate. Other factors affecting crack growth might be the properties of the grain boundary itself, the properties of the matrix, the presence of constituents, and the interaction of adjoining cracks.

We appreciate the comments of Mr. Dolan on the work of Love. His question as to whether slip actually occurred in times less than those plotted in the figures, but which was undetectable by the methods of investigation, is a hard one to answer. The curves of the amount of slip *versus* cycles seem to extrapolate smoothly without inflections to the origin, although this cannot be determined with certainty. This would indicate the presence of slip at a very few cycles but of insufficient severity to be detected. The methods of this investigation were very sensitive, but it is conceivable that still more sensitive methods would detect slip earlier. The data of the figures were obtained using the optical microscope, but some effort was made to find earlier slip using the electron microscope. A great deal of submicroscopic slip was observed with the electron microscope, but in no case was such slip observed on a specimen which did not show slip visible with the light microscope. This, however, is not sufficient evidence of the absence of slip at short periods of testing, for, being an exponential function of the number of cycles, slip is exceedingly rare at these times and could have been missed by the limited areas covered by the electron microscope replicas.

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[6] B. J. Lazan, "A Study with New Equipment of the Effects of Fatigue Stress on the Damping Capacity of Mild Steel," *Transactions*, Am. Soc. Metals, Vol. 42, p. 499 (1950).

AN EXPERIMENTAL STUDY OF THE INFLUENCE OF FLUCTUATING STRESS AMPLITUDE ON FATIGUE LIFE OF 75S-T6 ALUMINUM*

By H. T. Corten,[1] G. M. Sinclair,[1] and T. J. Dolan[1]

Synopsis

A study was made of the influence of fluctuating stress amplitude on the fatigue life of 75S-T6 aluminum. The pattern of fluctuating stress consisted of repeated blocks of 10,000 cycles during which a minor or low stress amplitude was applied during the initial portion and a major or high stress amplitude was applied during the remainder of the cycles in each repeated block. Various major and minor stresses as well as various percentages of cycles at the major stress were employed. Nine series of data, each consisting of 20 specimens, were collected. The data were analyzed statistically to obtain values of mean fatigue life and standard deviation of known reliability. It was shown that the life for fluctuating stress amplitude may be best correlated with the life at the major stress (constant amplitude). The life at the minor stress (constant amplitude) has only a small influence on the life for fluctuating stress amplitude. When the major stress was applied for only 5 per cent of the cycles in each block, an unexpectedly long life resulted. The standard deviations for fluctuating and constant stress amplitude data were compared.

In the past 100 years increased design stresses and longer service life of many machine parts have led to greater consideration of failure by progressive fracture. To achieve the desired performance, design of members such as aircraft structures and automotive parts are often based on a limited service life. One of the problems that has emerged as an important consideration in such designs is the influence of occasional cycles of overstress on the fatigue life of parts (**1**, **2**).[2]

Studies to determine the magnitude spectrum and frequency of occurrence of loads encountered in service have been made (**1**, **2**), and refined methods of stress analysis are available; however, the problem of accurately estimating the fatigue life of members subjected to fluctuating stress amplitudes remains unsolved. Although many experimental studies of the effect of fluctuations of stress amplitude on fatigue life have been made, only qualitative conclusions are available (**3**). This is not surprising in view of the fact that the fundamental mechanisms of progressive fracture are not well understood and the number of important parameters and variation of fatigue life are large.

To simplify quantitative interpretation of experimental results caused by the large variation of life, the application of statistical methods is useful. From the statistical representation of results, a measure of known reliability of central tendency (mean) of fatigue life and variation about the mean may be obtained.

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13–18, 1954.

[1] Assistant Professor, Associate Professor, and Research Professor, respectively, Department of Theoretical and Applied Mechanics, University of Illinois, Urbana, Ill.

[2] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 752.

Approximate methods for predicting fatigue life of members subjected to fluctuating stress amplitude have been suggested by several investigators (**4, 5, 6, 7**). It is generally agreed, however, that the proposed methods for appraising cumulative damage lack rational physical basis. Thus even when a statistical analysis is employed, it is not surprising that the experimental results, in terms of a mean number (or median number) of cycles, seldom agree with the number of cycles computed by these methods (**7–12**).

In general, it is necessary to predict the life of a member that will be subjected to known groups of stress cycles of various stress amplitudes applied in a random order. Since techniques for obtaining and analyzing such data may be complex, several investigators have studied the effects of prestressing at one amplitude followed by testing to failure at a different stress amplitude. The results of such investigations indicate that the order of applying the high and low stress is important. Consequently, it is not clear how the information obtained from this type of experiment can be applied to practical problems in which the various stress amplitudes are repeatedly applied in a random order.

The type of experimental information that will be useful in formulating a more accurate theory of cumulative damage should come from experiments in which the several stress amplitudes are mixed so that the influence of the order of applying the stresses is minimized. By employing a relatively short group of stress cycles in a repeated pattern, analysis of the data may be facilitated since the per cent of the total number of cycles at each stress amplitude remains approximately constant, irrespective of the life of the individual specimen.

PURPOSE AND SCOPE

This paper presents the results of an experimental investigation of an aluminum alloy subjected to fluctuating stress amplitude. Nine series of data are included, each of which summarizes the results obtained from 20 specimens. For each series the stress amplitude was alternated between a high or major stress and a low or minor stress. Repeated blocks of 10,000 cycles were employed in which the major stress was applied 5000, 1000, or 500 cycles during each block. This corresponds to the application of cycles of major stress for approximately 50, 10, and 5 per cent, respectively, of the fatigue life of each specimen. To simplify the terminology, these series will be identified hereafter as the 50 per cent series, 10 per cent series, and 5 per cent series.

The experimental design permitted a statistical analysis of the data from which a measure of central tendency of fatigue life and variation of known reliability was obtained. By employing only two stress amplitudes in any given series, the interaction of these two stress amplitudes may be studied. The data were analyzed by comparing the experimentally determined mean values of fatigue life with those predicted on the assumption that damage was linearly cumulative at the major stress only. Standard deviations for the fluctuating and constant stress amplitude experiments were also compared.

EXPERIMENTAL INVESTIGATION

The material employed was a 75S-T6 aluminum alloy, in the form of $\frac{7}{8}$-in. diameter rods, that was used in the "as received" condition. Small, high-speed, rotating-bending specimens with dimensions as shown in Fig. 1 were machined from each half after splitting the bars longitudinally. The specimens were polished mechanically according to a standard procedure (**13**). The tensile properties and hardness have been given in a previous report (**14**).

The loading sequence consisted of subjecting specimens to completely reversed alternating stress that varied between two stress amplitudes in repeated blocks of 10,000 cycles. The minor stress was applied during the initial portion of each repeated block of cycles, and the major stress was applied during the remainder of each block as shown schematically in Fig. 2. The various combinations of major and minor stress and per cent of cycles at the major stress are listed in Table I. Twenty specimens were tested for each series listed in Table I to obtain a reliable measure of the mean life and standard deviation. The machines employed to obtain this fluctuating stress amplitude have been described previously by Dolan, Richart, and Work (**3**). However, since the question will later arise, it is desirable to discuss briefly the mechanism employed to change from the minor to the major stress amplitude. The minor stress was set directly on the loading beam employed for constant stress amplitude experiments. The major stress was obtained by adding an additional weight to the loading arm. The application (and removal) of this weight was controlled by a cam which made one revolution for every 10,000 cycles of the specimen. Approximately 1 per cent of the cycles in each repeated block were required to apply the additional load and remove it. The cam and additional weight were adjusted so that the period of transition from minor to major (and *vice versa*) stress was subtracted approximately equally from the number of cycles at the minor and major stresses. Consequently, approximately 1 per cent must be subtracted from the nominal values of per cent of cycles at the major (and minor) stress for the transition period.

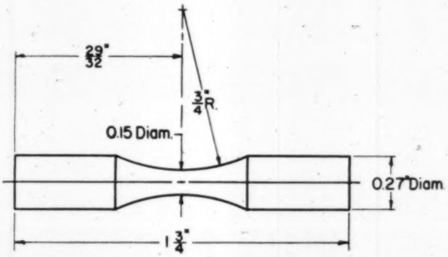

Fig. 1.—Dimensions of Fatigue Specimen.

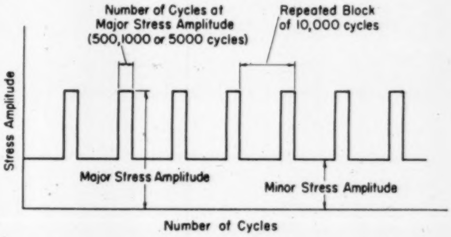
Number of Cycles at Major Stress Amplitude (500, 1000 or 5000 cycles)
Repeated Block of 10,000 cycles
Stress Amplitude
Major Stress Amplitude
Minor Stress Amplitude
Number of Cycles

Fig. 2.—Loading Sequence Employed in Fluctuating Stress Amplitude Experiments.

A summary of the experimental values of fatigue life for both the variable and constant stress amplitude series is given in Table I. The data for constant stress amplitude was taken from the work of Sinclair and Dolan (**14**) on specimens from the same heat tested in the same machines. Because in Sinclair and Dolan's original data for constant stress amplitude the point at 50,000 psi appeared to be out of line with the rest of the data, an additional 20 specimens were tested to check this point. The mean value of log N for the first group of 20 specimens was 4.7234 as compared with a value of 4.7308 for the new data. As this difference is not significant at the

TABLE I.—SUMMARY OF EXPERIMENTAL FATIGUE LIFE DATA.

Major Stress, psi	Minor Stress, psi	Per cent of Cycles at Major Stress	Number of Specimens	Mean Log Life, $\overline{\log N}$	95 per cent Confidence Limits for $\overline{\log N}$	Standard Deviation, σ	90 per cent Confidence Limits for σ
VARIABLE STRESS AMPLITUDE							
40 000........	30 000	50	20	5.4444	5.5873-5.3014	0.3604	0.5064-0.2936
40 000........	30 000	10	20	5.9221	6.0212-5.8229	0.2500	0.3513-0.2036
50 000........	30 000	50	20	4.9754	5.0147-4.9361	0.0993	0.1399-0.0809
50 000........	30 000	10	20	5.4238	5.4666-5.3811	0.1078	0.1515-0.0879
50 000........	30 000	5	20	6.2525	6.3525-6.1525	0.2525	0.3550-0.2058
50 000........	40 000	50	20	4.7375	4.7694-4.7055	0.0806	0.1133-0.0656
50 000........	40 000	10	20	5.3189	5.3743-5.2634	0.1437	0.1998-0.1175
39 800........	34 100	10	21	5.9605	6.0432-5.8788	0.2085	0.2929-0.1697
45 500........	34 100	5	20	6.2495	6.3946-6.1044	0.3658	0.5139-0.2982

CONSTANT STRESS AMPLITUDE (**14**)

Stress, psi	Number of Specimens	Mean Log Life, $\overline{\log N}$	95 per cent Confidence Limits for $\overline{\log N}$	Standard Deviation, σ	90 per cent Confidence Limits for σ
30 000............	57	7.2120	7.3216-7.1024	0.4130	0.4776-0.3484
35 000............	17	6.1674	6.2841-6.0507	0.2270	0.3316-0.1825
40 000............	39	5.3331	5.4158-5.2504	0.2443	0.2930-0.1956
45 000............	20	4.7585	4.8344-4.6826	0.1273	0.1790-0.1040
50 000............	40	4.7270	4.7614-4.6927	0.1085	0.1530-0.0884
62 500............	21	4.2047	4.2210-4.1884	0.0348	0.0484-0.0284

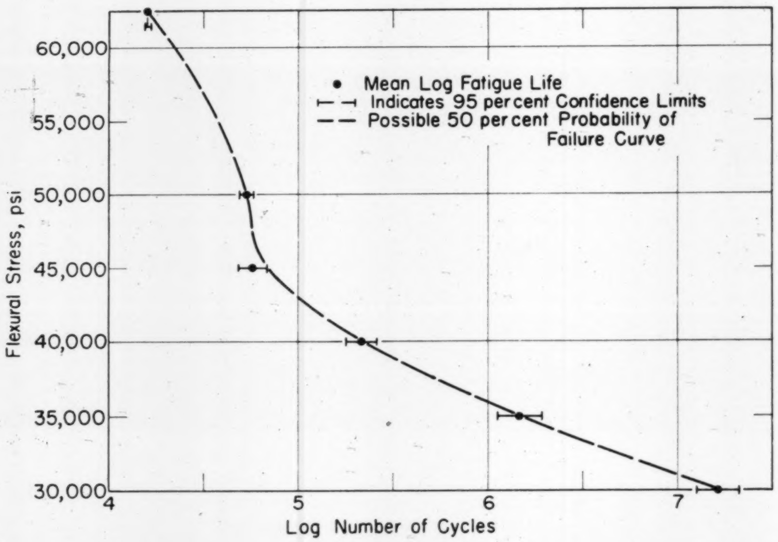

FIG. 3.—Fatigue Life Diagram for Constant Stress Amplitude.

5 per cent probability level, these two sets of data have been combined in Table I. The stress - log N diagram for constant stress amplitude is shown in Fig. 3. As there is no known reason for a sharp break in the curve, it seems likely that a smooth curve such as the dashed curve in Fig. 3 contained within the confidence limits may best represent the variation of fatigue life (for 50 per cent probability of failure) with stress.

DISCUSSION OF RESULTS

Statistical analysis of small samples (20 specimens) to include confidence limits requires that the distribution be approximately normal. It has been shown that for fatigue life data from constant stress amplitude experiments the logarithms of the fatigue life N approximate a normal distribution. To study the distribution of log N for variable stress amplitude data, log normal probability diagrams were prepared and are shown in Fig. 4. The straight lines in this figure represent the theoretical log - normal frequency distribution (based on the values of mean log N and standard deviation computed from the data). Judging from the 20 specimen samples, it appears that the log normal distribution is a reasonable approximation to the observed frequency distribution of fatigue life. Consequently, mean log N (log N) will be adopted as a measure of central tendency of fatigue life and used throughout the remainder of this paper. The 95 per cent confidence limits for mean log N, the standard deviation, and the 90 per cent confidence limits for the standard deviation are included in Table I. The correlation between the standard deviations for constant and variable stress amplitude data will be discussed later.

Assumption That Damage Occurs at the Major Stress Only:

For loading sequences consisting of various numbers of cycles of only two stress amplitudes, it seems likely that stressing at the major stress amplitude develops the larger contribution to damage. To examine this idea, it is instructive to assume that damage occurs *only* when the major stress is applied and that fracture occurs when the sum of the number of cycles at the major stress amplitude is equal to the number of cycles to fracture for a constant stress amplitude at this stress.[3] The damage from cycles of the minor stress might now be interpreted as the difference between the experimentally determined life and that computed by assuming damage at the major stress only. This leads to the expectation that, for a given combination of major and minor stresses, the greater the proportion of cycles at the minor stress, the greater the damage contributed by the minor stress. To examine the experimental results from this point of view, the per cent of cycles at the major stress is plotted *versus* mean log life (log N) in Figs. 5 through 8. The solid curves in Figs. 5 through 8 correspond to the expected fatigue life for various percentages of cycles at the major stress assuming that damage is linearly cumulative during cycles of the major stress only; that is, the sum of the cycles of major stress is constant at fracture. In addition to this curve, a lower and an upper limit are set by the life from constant stress amplitude experiments at the major and minor stresses, respectively. These limits presume that no metallurgical changes (precipitation hardening or strain aging) occur during the variable stress ampli-

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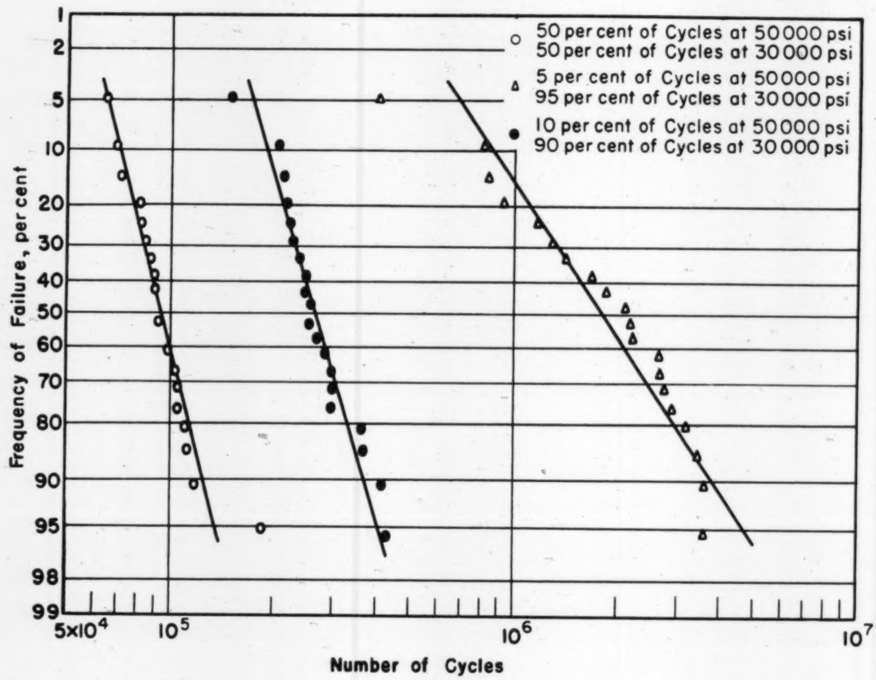
[3] This approach is similar to that proposed by Stickley (**15**).



(*a*)

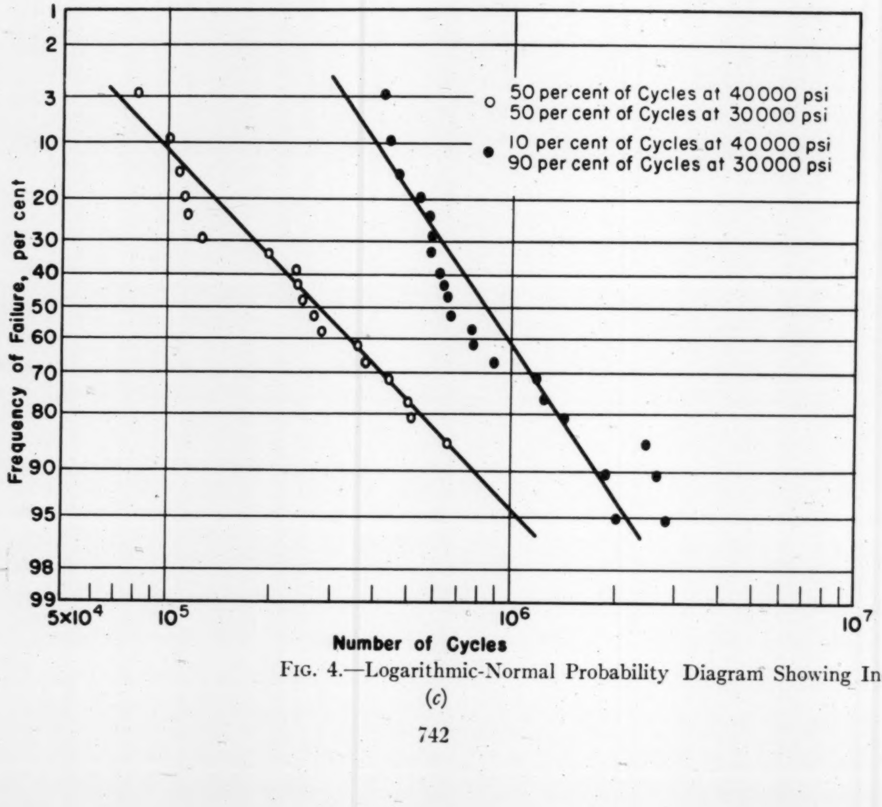
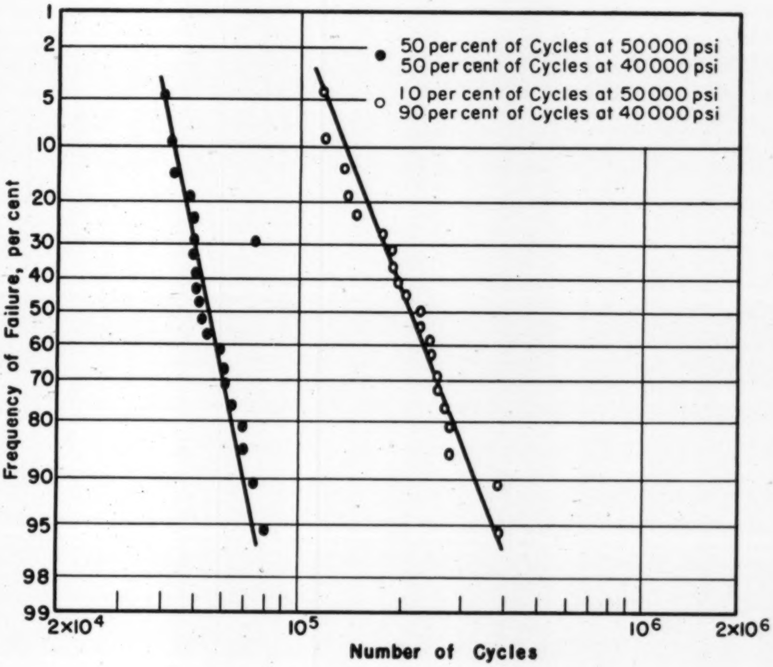
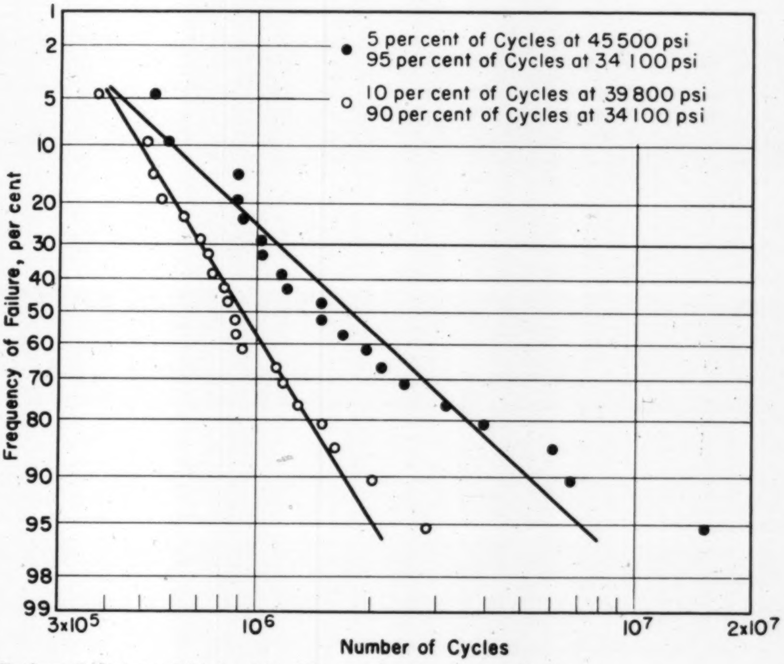


FIG. 4.—Logarithmic-Normal Probability Diagram Showing Indi

(*c*)



(*b*)



vidual Fatigue Lifetimes Obtained for Fluctuating Stress Amplitude.

(*d*)

tude test. For the precipitation hardened 75S-T6 aluminum employed in these experiments, this assumption seems reasonable. For purposes of comparison, the life predicted by the assumption that the cumulative cycle ratio is equal to one is also included.[4]

An examination of Figs. 5 through 8 reveals the following characteristics:

1. For the 50 and 10 per cent series, the experimental data lie to the left of the solid curve that is based on the hypothesis that damage occurs at the major stress only. The difference between the fatigue life given by this curve and the experimental data may be interpreted as a measure of the decrease in life due to cycles of the minor stress. In each case, this difference is greater for the 10 per cent series than for the 50 per cent series. This confirms the qualitative expectation that the larger the percentage of cycles at the minor stress the greater their relative contribution to the total damage.[5]

2. For the two 5 per cent series, the experimental data lie to the right of the solid curve for damage at the major stress only. In attempting to determine the cause of this unexpected long life, it should be noted that for the 5 and 10 per cent series the per cent of cycles at the minor stress is nearly the same. Consequently it appears that this unexpected long life might be attributed to a smaller amount of damage contributed by cycles of major stress. That is, it appears that in two blocks of the 5 per cent series less damage is done than in one block

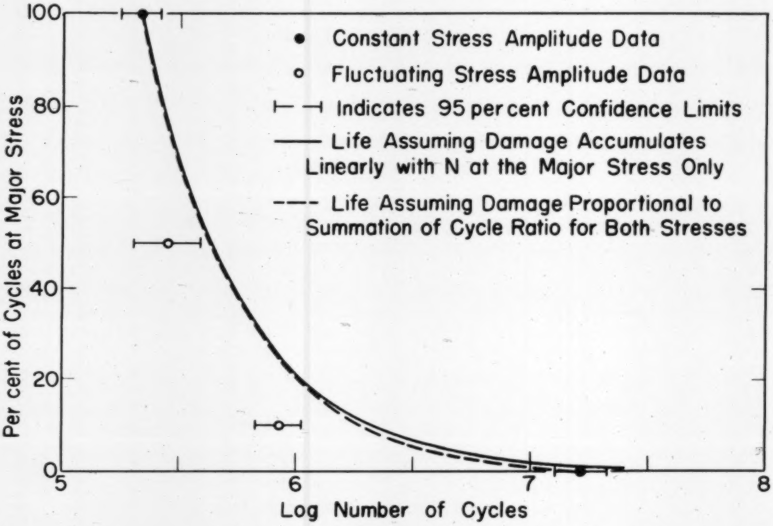


FIG. 5.—Effect of Per Cent of Cycles at Major Stress on the Mean Log Fatigue Life for a Major Stress of 40,000 psi and a Minor Stress of 30,000 psi.

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[4] Cumulative cycle ratio is defined as $\Sigma \frac{n}{N}$ where n is the number of cycles at a given stress and N is the number of cycles to produce failure at that stress as determined from an S-N diagram. As this assumption requires that the computations be carried out in terms of N and *not* log N, the antilog of mean log N was employed. An analysis of the data in terms of cumulative cycle ratio employing mean N and median N as measures of central tendency of fatigue life is given in Appendix A.

[5] This difference is small when life is measured in terms of log N; however, in terms of N the differences are much larger.

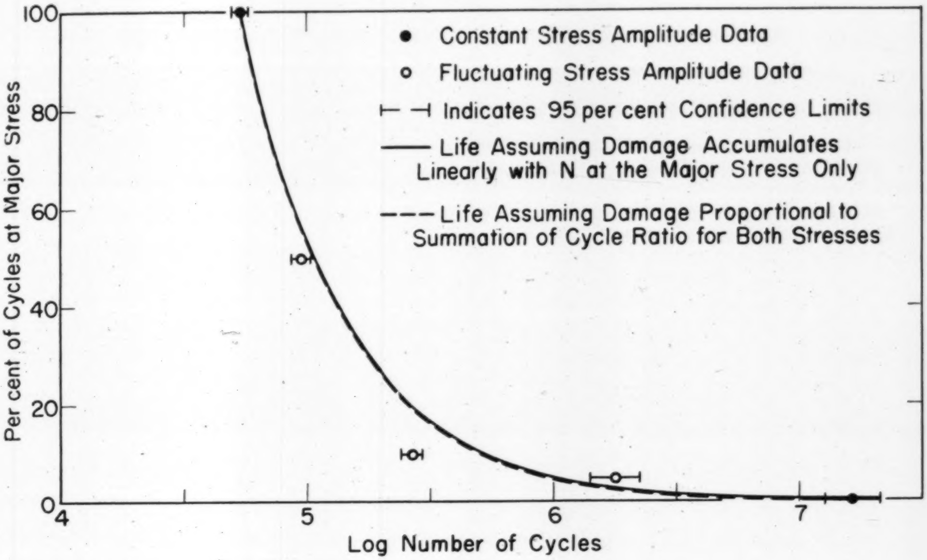

FIG. 6.—Effect of Per Cent of Cycles at Major Stress on the Mean Log Fatigue Life for a Major Stress of 50,000 psi and a Minor Stress of 30,000 psi.

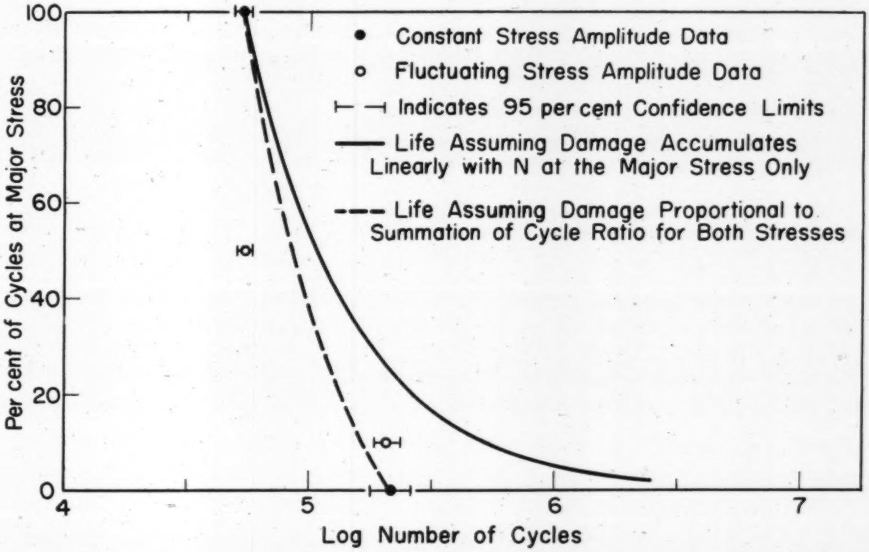

FIG. 7.—Effect of Per Cent of Cycles at Major Stress on the Mean Log Fatigue Life for a Major Stress of 50,000 psi and a Minor Stress of 40,000 psi.

of the 10 per cent series even though the total number of cycles at the major stress is the same. This suggests that, during the first few cycles at a major stress amplitude, either damage does not accumulate linearly with numbers of cycles or a nucleation period for the initiation of damage occurs.

3. The life for constant amplitude at the minor stress which may constitute an upper limit on the life for fluctuating stress amplitude appears to have only a small influence on the life for variable stress amplitude experiments. To clarify this statement, "per cent of cycles at the major stress" is plotted in Fig. 9 as a function of the decrease in total life observed in the fluctuating load tests (that is, log $\overline{N}$ − log $\overline{N}_{\text{major}}$ where log $\overline{N}$ and log $\overline{N}_{\text{major}}$ are the mean log life from variable and constant major stress amplitude experiments, respectively). This method of plotting superimposes the data of Figs. 5 through 8 in such a way that the solid curves coincide. In Fig. 9 the lives from constant stress amplitude experiments at the minor stress are shown for each of the various series. It will be noted that, regardless of the life (for a constant amplitude) at the minor stress, the data for fluctuating stress amplitudes tend to cluster together for all three percentages of major stress. This fact is particularly evident for the 10 and 5 per cent series.

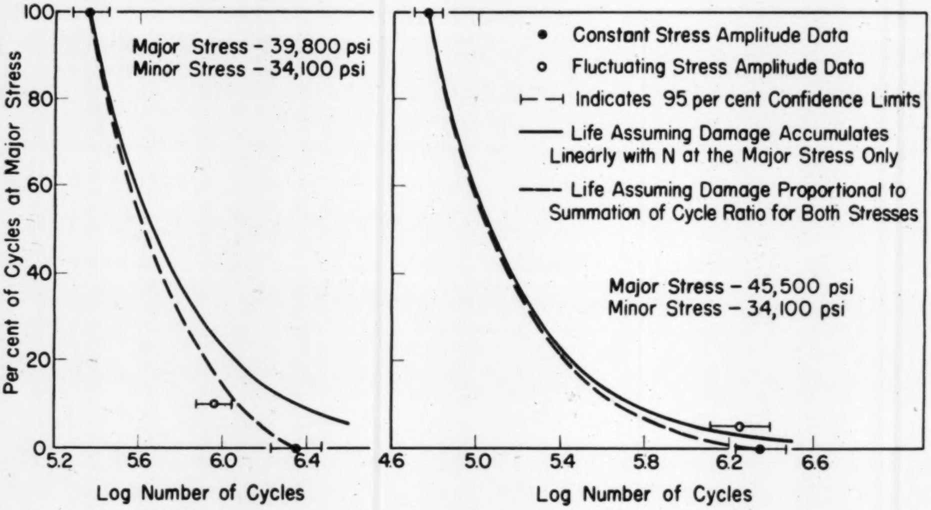

FIG. 8.—Effect of Per Cent of Cycles at Major Stress on Mean Log Fatigue Life.

The small influence of the life at the minor stress is indicated by the following observations: (*a*) In two instances—the 10 per cent series with a major and minor stress of 50,000 and 40,000 psi, respectively, and the 5 per cent series with a major and minor stress of 45,500 and 34,100 psi, respectively—the life is not significantly different[6] from that observed at the respective constant minor stress amplitudes. (*b*) However, in other series, the life from constant stress amplitude experiments at the minor stress was much longer than the life for the fluctuating stress amplitude data. These observations suggest that the life at the minor stress is not a significant factor in determining the life under conditions of variable stress amplitude. It is true that in the extreme instances involving major and minor stresses of 50,000 and 40,000 psi on the one hand and 50,000 and 30,000 psi on the other there is a small but significant difference for the 50 and 10 per cent series. In all other series, however, the 95 per cent confidence limits overlap and therefore, within the limits of reliability of the data, no difference can be established. As a corollary to these observations, it is suggested that the magnitude of the minor stress exerts only a small influence on the life for conditions of fluctuating stress amplitude.

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[6] This refers to significance at the 5 per cent level.

4. It was suggested earlier that the life obtained from constant stress amplitude experiments at the minor stress constitutes an upper limit of life for the condition of fluctuating stress amplitude. That is, when the per cent of cycles at the major stress is reduced to the point where the life for fluctuating stress amplitude is equal to the life for constant minor stress amplitude, further reduction in the per cent of cycles at the major stress will not increase the life obtained from fluctuating stress amplitude. While this appears logical for this material and no exceptions occur in the present data, the experiments do not prove this point. For a major and minor stress of 50,000 and 40,000 psi, respectively, the life for the 10 per cent series is not significantly different from the life from constant stress amplitude experiments at the minor stress. It would be interesting to know the life for this combination of major and minor stress when the major stress is applied only 5 per cent of the cycles.

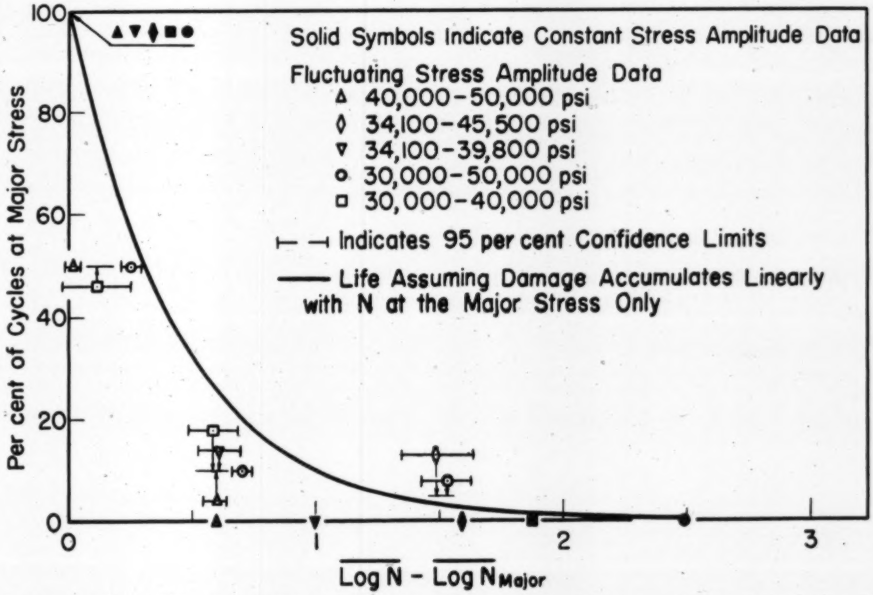

FIG. 9.—Effect of Per Cent of Cycles at Major Stress on the Difference Between the Mean Log Fatigue Life for Fluctuating and Constant Major Stress Amplitude Data.

Variability of Fatigue Life:

A complete description of the fatigue life distribution requires a measure of both the mean and variation about the mean. Whereas the mean fatigue life resulting from various combinations of fluctuating stress amplitude has been the subject of numerous investigations, no such background information exists with respect to the variation about the mean. In fact, it is only in recent years that the variation about the mean has been studied for constant stress amplitude data, and information on this aspect of the problem is far from complete. From the information available for this material, 75S-T6 aluminum, the standard deviation decreases as the stress amplitude increases (**14**). However, the method of making a straightforward comparison of variability (or standard deviation) between constant and fluctuating stress amplitude data on the basis of stress level is not immediately clear. Consequently, two methods of comparison have been studied, as follows:

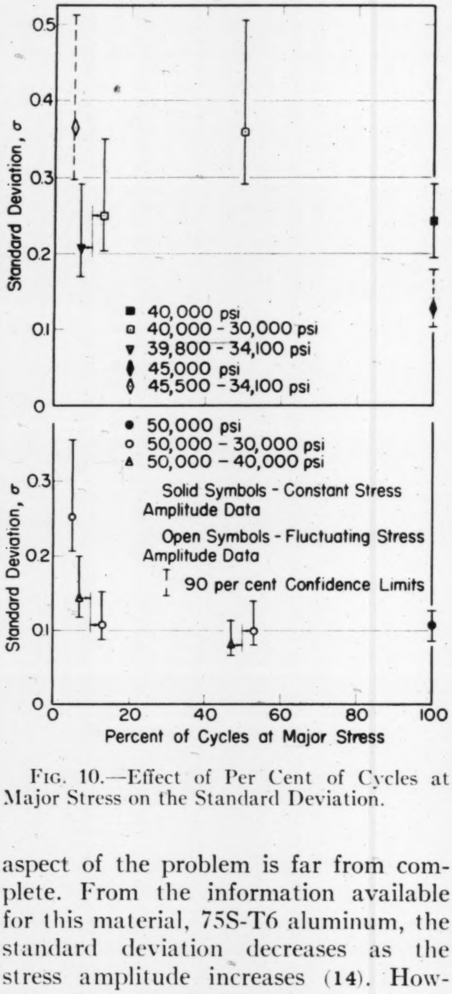

FIG. 10.—Effect of Per Cent of Cycles at Major Stress on the Standard Deviation.

1. From the study of the mean fatigue life for various combinations of fluctuating stress, it was found that the major stress exerted the predominant influence on the life. Consequently it seems reasonable to expect that the standard deviation of mean log life for conditions of fluctuating stress amplitude may be closely associated with the standard deviation obtained from constant stress amplitude experiments at the major stress. In Fig. 10 the standard deviation has been plotted *versus* the per cent of cycles at the major stress. Also included in this figure are the 90 per cent confidence limits from the fluctuating stress amplitude experiments and for constant stress amplitude at the various major stresses. A study of this figure discloses that with one exception the 90 per cent confidence limits for the fluctuating and constant stress amplitude data overlap for the 10 and 50 per cent series. This indicates that no significant difference between the standard deviations can be established. The one exception is the 50 per cent series for a major and minor stress of 40,000 and 30,000 psi, respectively. The 90 per cent confidence limits do not quite meet; however, the difference (see Table I) is so small that it appears unwise to draw any conclusions concerning this discrepancy based on the results of only 20 specimens.

For the 5 per cent series, the standard deviations were larger than the standard deviation for constant stress amplitude data at the major stress. However, since the fatigue life for the 5 per cent series was longer than anticipated, the larger standard deviations should not be entirely unexpected and in fact may add additional support to the hypothesis that damage is not linearly cumulative during the first 500 cycles at the major stress amplitude.

2. From the observation that as the stress (constant stress amplitude) decreases the standard deviation and also the life increase, it appears that the observed fatigue life may provide a rough index to the variation of the standard deviation. In Fig. 11 the standard deviation has been plotted *versus* mean log N ($\overline{\log N}$) for both the constant and fluctuating stress amplitude data. It is clear that, although a general trend is present, the correlation between the constant and fluctuating stress amplitude data based on mean log life is not good. Whereas this procedure tends to better correlate the data for the 5 per cent series, the data for which good correlation was obtained in Fig. 10 now appear out of line. The correlation of the one set of data which exhibited an unexpectedly large standard deviation noted in connection with Fig. 10 (50 per cent at 40,000–30,000 psi) is not improved by plotting standard deviation *versus* $\overline{\log N}$.

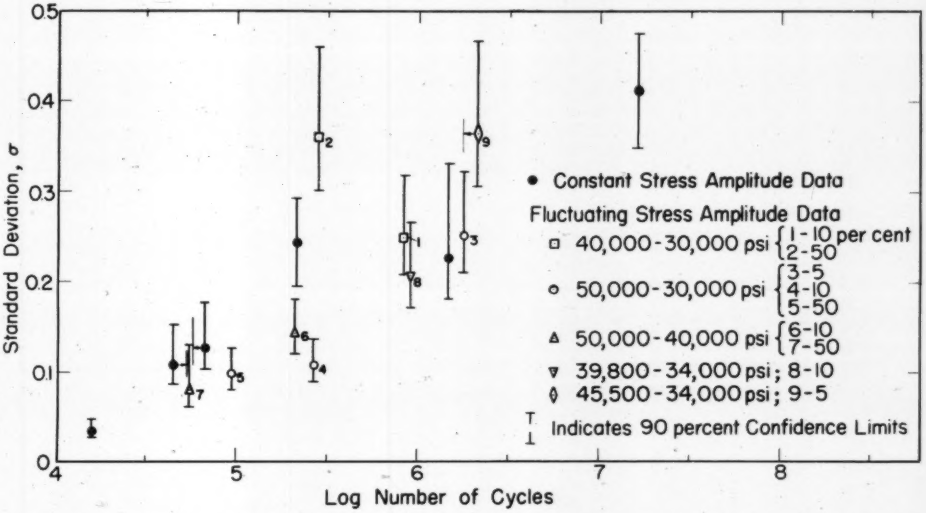

FIG. 11.—Variation of Standard Deviation for Constant and Fluctuating Stress Amplitude Data with Fatigue Life.

SUMMARY AND CONCLUSIONS

An experimental program was designed to study two aspects of the problem of the influence of fluctuating stress amplitude upon fatigue life of 75S-T6 aluminum. The two aspects were (1) the interaction between various amplitudes of major (high) and minor (low) stress and (2) the influence of the per cent of cycles at the major (high) stress. For this purpose specimens were subjected to repeated blocks of 10,000 cycles, during which the stress amplitude was maintained at the minor stress for a certain percentage of cycles in each repeated block and then rapidly shifted to the major stress amplitude for the remainder of the cycles in each block. In this way each specimen, regardless of its fatigue life, was subjected to approximately the same per cent of cycles at the major and minor stresses. Various magnitudes of major and minor stress were employed as well as various percentages of cycles at the major stress. Nine series of data, each containing 20 specimens, were collected. The data were analyzed statistically to obtain values of mean log N and standard deviation of known reliability.

Within the limits imposed during the investigation, the following conclusions appear to be justified:

1. The fatigue life frequency distribution resulting from fluctuating stress amplitude may be represented approximately by a log-normal distribution.

2. The magnitude and per cent of cycles of major stress were the most important factors in determining the mean fatigue life (log N).

3. The rate at which damage accumulates during the first few cycles (500) each time a major stress was applied was lower than the rate at which it accumulates during an equal number of cycles later in a continuous sequence of cycles at the major stress. For example, the damage accumulated during two repeated blocks of a 5 per cent series was less than the damage accumulated during one block of a 10 per cent series (same major and minor stresses) even though the number of cycles of major stress was the same.

4. The contribution of cycles of minor stress to damage appeared to increase as the per cent of cycles at the minor stress increases. However, the amplitude of the minor stress, the life at the minor stress, or the stress increment between the major and minor stress had only a small influence upon the contribution of cycles of minor stress to damage for the range studied. It was only in the extreme cases (judged on the basis of life at the minor stress) that a significant difference between the contribution to damage of two different minor stresses could be established.

5. No completely satisfactory method of correlating the standard deviations obtained from constant and fluctuating stress amplitude data was found. In general, the standard deviation for fluctuating stress amplitude data was not significantly different from the standard deviation for constant stress amplitude data at the major stress for either the 10 or 50 per cent series. However, for the 5 per cent series, the observed standard deviations were significantly larger than those from constant stress amplitude experiments at the major stress. It appears that this difference and the unexpectedly long life for the 5 per cent series may be closely associated with the phenomena discussed in conclusion 3. When the standard deviation was compared to mean log N for both constant and fluctuating stress amplitude data, a general trend was present; however, the correlation was not good.

Acknowledgment:

This investigation was conducted in the research laboratories of the Department of Theoretical and Applied Mechanics as part of the work of the Experiment Station, University of Illinois, in cooperation with the Office of Naval Research, United States Navy, under Contract N6-ori-071(04). Acknowledgment is due to Mrs. D. Klausmeyer for typing the manuscript and G. L. Lovestrand for preparing the illustrations.

APPENDIX A

For the purpose of comparing the results of the present investigation with those of previous investigations, the cumulative cycle ratios ($\Sigma \frac{n}{N}$) were computed for each series of data. When the results of a group of specimens (20 in each series) are available, it has been customary to employ mean N or median N as a measure of fatigue life. The mean and median values of N (fatigue life) along with the cumulative cycle ratios obtained by employing each of these measures of fatigue life are shown in Table II. A study of the values of cumulative cycle ratios indicates that they do not approach a value of one or any other constant value as has been suggested by several investigators (**4, 5**). Also there appear to be no consistent trends in the values of cumulative cycle ratio. Consequently, it appears that this method of predicting fatigue life is not reliable, at least not for the pattern of fluctuating stress amplitude employed in these experiments.

TABLE II.—FATIGUE LIFE IN TERMS OF MEAN N, MEDIAN N, AND CORRESPONDING CYCLE RATIOS.

VARIABLE STRESS AMPLITUDE

Major Stress, psi	Minor Stress, psi	Per cent of Cycles at Major Stress	Mean Life[a] $\bar{N}$	Median Life[a] $\check{N}$	$\sum \frac{n}{N}$ Based on $\bar{N}$	$\sum \frac{n}{N}$ Based on $\check{N}$
40 000..........	30 000	50	441	256	0.843	0.670
40 000..........	30 000	10	1116	658	0.466	0.372
50 000..........	30 000	50	97	92	0.889	0.940
50 000..........	30 000	10	274	252	0.510	0.527
50 000..........	30 000	5	2062	2126	1.96	2.27
50 000..........	40 000	50	56	52	0.612	0.666
50 000..........	40 000	10	220	224	1.15	1.50
39 800..........	34 100	10	1043	848	0.789	0.788
45 500..........	34 100	5	2730	1487	3.44	2.11

CONSTANT STRESS AMPLITUDE

Stress, psi	$\bar{N}$[a]	$\check{N}$[a]
30 000............................	23 320	19 117
35 000............................	1 655	1 400
40 000............................	264	193
45 000............................	60.0	52.5
50 000............................	54.8	49.0
62 500............................	16.1	16.5

[a] Life in thousands of cycles.

REFERENCES

(1) J. J. Saunders and A. B. Callender, "Some Observations About the Fatigue Life of Aircraft Structures," *Engineering Report No. 3854,* The Glenn L. Martin Co., March, 1952.

(2) H. L. Dryden, R. V. Rhode, and P. Kuhn, "The Fatigue Problem in Airplane Structures," *Fatigue and Fracture of Metals,* W. M. Murray, Editor, M.I.T. Press and John Wiley and Sons, Inc., New York, N. Y. (1952). Presented as a symposium at Massachusetts Institute of Technology.

(3) T. J. Dolan, F. E. Richart, and C. E. Work, "The Influence of Fluctuations in Stress Amplitude on the Fatigue of Metals," *Proceedings,* Am. Soc. Testing Mats., Vol. 49, p. 646 (1949).

(4) M. A. Miner, "Cumulative Damage in Fatigue," *Transactions,* Am. Soc. Mechanical Engrs., Vol. 67, p. A159 (1945).

(5) B. F. Langer, "Fatigue Failure from Stress Cycles of Varying Amplitude," *Transactions,* Am. Soc. Mechanical Engrs., Vol. 59, p. A160 (1937).

(6) N. M. Newmark, "A Review of Cumulative Damage in Fatigue," *Fatigue and Fracture of Metals,* W. M. Murray, Editor, M.I.T. Press and John Wiley and Sons, Inc., New York, N. Y. (1952). Presented as a symposium at Massachusetts Institute of Technology.

(7) F. R. Shanley, "A Theory of Fatigue Based on Unbonding During Reversed Slip," *P-350-1,* The Rand Corp., Santa Monica, Calif., November, 1952, and *P-350 Supplement,* May, 1953.

(8) T. J. Dolan and H. F. Brown, "Effect of Prior Repeated Stressing on the Fatigue Life of 75S-T Aluminum," *Proceedings,* Am. Soc. Testing Mats., Vol. 52, p. 733 (1952).

(9) G. E. Dieter, G. T. Horne, and R. F. Mehl, "Investigation of the Statistical Nature of the Fatigue of Metals," Metals Research Lab., Carnegie Institute of Technology, NACA Contract NAw-6132, May, 1953. Unpublished report.

(10) H. F. Hardrath and E. C. Utley, "An Experimental Investigation of the Behavior of 24S-T4 Aluminum Alloy Subjected to Repeated Stress of Constant and Varying Amplitude," *Technical Note No. 2798,* Nat. Advisory Comm. Aeronautics, October, 1952.

(11) S. Luthander and G. Wållgren, "Determination of Fatigue Life with Stress Cycles of Varying Amplitude," *FFA Report No. 18,* The Aeronautical Research Institute of Sweden (1949).

(12) G. Wållgren, "Fatigue Tests with Stress Cycles of Varying Amplitude," *FFA Report No. 28,* The Aeronautical Research Institute of Sweden (1949).

(13) Manual on Fatigue Testing, Am. Soc. Testing Mats., p. 35 (1949). (Issued as separate publication *ASTM STP No. 91.*)

(14) G. M. Sinclair and T. J. Dolan, "Effect of Stress Amplitude on the Statistical Variability in Fatigue Life of 75S-T6 Aluminum Alloy," *Transactions,* Am. Soc. Mechanical Engrs., Vol. 75, p. 867 (1953).

(15) G. W. Stickley, "Effect of Alternating High and Low Repeated Stresses upon the Fatigue Strength of 25S-T Aluminum Alloy," *Technical Note No. 792,* Nat. Advisory Comm. Aeronautics (1941).

DISCUSSION

Mr. George R. Gohn.[1]—Fatigue results are sometimes rather difficult to interpret, so that the introduction of a different concept or a different method of plotting makes it a bit difficult to follow the thesis which the authors are trying to develop. I would urge that they consider plotting all of the test results to a conventional scale unless there is some definite advantage in using the logarithm of the number of cycles.

Mr. R. E. Peterson.[2]—For want of something better the cumulative cycle ratio $\sum\frac{n}{N} = A$ has been used in design with $A = 1$. This has given reasonable results in connection with railway axles and also in the aircraft field. In view of the spread of A found in laboratory tests, one cannot help wondering why the past procedure has been at all satisfactory. Incidentally, this is not a matter of being covered by a large factor of safety, since for railway axles the life before initiation of fatigue cracks has been predicted within a reasonable range.

Two points should be noted with regard to the service applications mentioned. First, the stress amplitudes are "mixed" with regard to the time scale, so that results from step-up or step-down tests (that is, testing at one stress level for a given number of cycles followed by the remainder at another stress level) would not be expected to be applicable in this instance. Second, in service a small number of cycles usually occur at the higher stress levels as compared to the larger numbers of cycles at lower levels. In laboratory tests various ratios of high and low stresses are used, sometimes a 50 per cent ratio of total; while this information is all of basic value, much of it may not be applicable to the types of service cited.

With regard to the first point, the tests of the paper under discussion are of particular value since the stress pattern is repeated so that "mixing" occurs. With regard to the second point, it is interesting to note that the A values closest to unity occur where the higher stress operates 5 or 10 per cent of the time. It appears that operating somewhere between 5 and 10 per cent might have resulted in approximately $A = 1$ in this particular case.

As further evidence, curves for $A = 1$ are shown in heavy dashed lines (accompanying Fig. 12) on a plot of tests from the same laboratory[3] at a 10 per cent ratio. It will be noted that these are in reasonable agreement with the data and the full curves drawn by the authors to represent the data.

To speculate a bit, perhaps one might expect approximate agreement with $A = 1$ if the slope of the damage curve (and preferably also that of the S-N curve) would be in approximate accordance with the ratio of high and low stresses (or with the stress spectrum in general).

The authors' views in this respect

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[2] Manager, Mechanics Department, Westinghouse Research Laboratories, East Pittsburgh, Pa.

[3] T. J. Dolan, F. E. Richart, Jr., and C. E. Work, "The Influence of Fluctuations in Stress Amplitude on the Fatigue of Metals," *Proceedings*, Am. Soc. Testing Mats., Vol. 49, p. 646 (1949).

would be appreciated. The paper is an excellent one, particularly in view of the statistical procedures used to greatly enhance the validity of the results.

MESSRS. H. T. CORTEN, G. M. SINCLAIR, AND T. J. DOLAN (*authors' closure*).—The authors wish to thank the discussers for their comments. Mr. Gohn has raised the question of why the logarithm of the number of cycles was employed in the plotting of data in Figs. 5, 6, 7, and 8 instead of the more conventional procedure of plotting the number of cycles to a logarithmic scale. The logarithm of the number of cycles was employed to facilitate the procedure used in Fig. 9; that is, plotting the difference between two logarithms as the abscissa in this figure. The similarities between the various sets of data were most apparent when the data were plotted in this manner.

Mr. Peterson has made the interesting observation that in the range where the percentage of cycles at the high stress was small (10 per cent or less) the data indicated that the summation of the cycle ratios approached one. Because the results with small numbers of load cycles at the high stress were of particular interest to the authors, this study was subsequently extended to include series having 1, 2, 4, and 6 per cent of cycles at the high stress. The major stress was applied by employing controlled electrical current in a solenoid instead of by dead weights. The data obtained using this modified system are believed to be accurate, but these latter results do not agree entirely with those presented in the paper for the two series having 5 per cent of the cycles at the high stress. The lives for the 4 and 6 per cent series are considerably shorter than the 5 per cent series reported in the original paper. However, these later studies do confirm and agree with the results for those tests in which 10 per cent of the cycles were at the major stress. The reason for this discrepancy in the 5 per cent series is not known, and hence it appears unwise to draw any definite conclusions for this series.

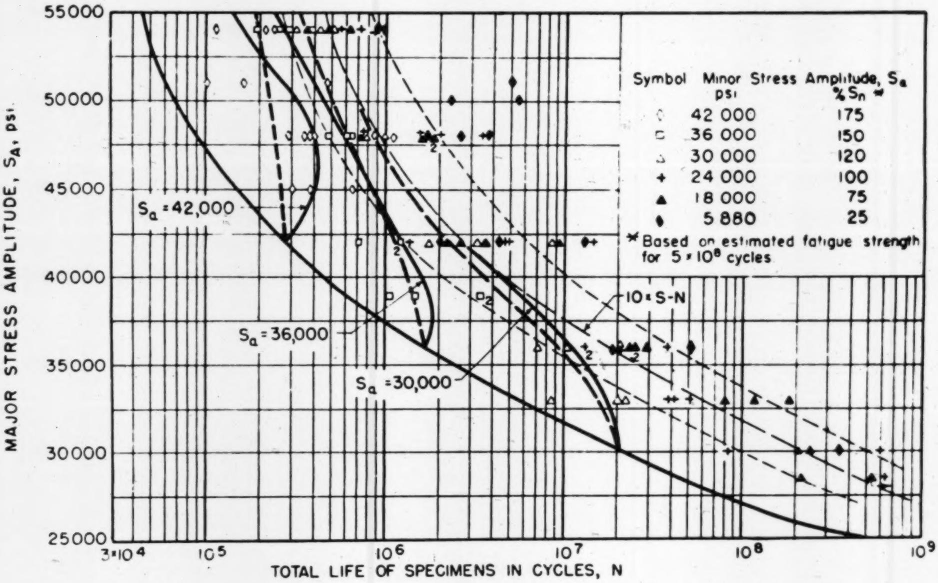

FIG. 12.—Test Results for Unnotched Specimens of 75S-T Aluminum Alloy with Cycle of 10 per cent S max and 90 per cent S min.

FATIGUE STRENGTH OF 14S-T4 ALUMINUM ALLOY SUBJECTED TO BIAXIAL STRESSES*

By R. W. Bundy[1] and Joseph Marin[2]

Synopsis

The purpose of this investigation was to determine the influence of biaxial tension-tension and biaxial tension-compression stresses on the fatigue strength of a 14S-T4 aluminum alloy. The biaxial fatigue stresses were produced in a specially designed testing machine by subjecting a circular thin-walled tubular specimen simultaneously to pulsating internal pressure and fluctuating axial tension or compression. The influence of various ratios of the biaxial stresses on the fatigue strength was investigated.

The test results show that the fatigue strength is greatly affected by the anisotropy of the material. Attempts are made in this paper to interpret the test results by using a modified energy theory of failure which provides for anisotropy of the material.

Although many machine and structural parts are subjected to combined fatigue stresses, most available fatigue strength data have been obtained for simple stresses such as fluctuating tension and bending. Furthermore, most investigations (**1** – **12**)[3] that have been conducted to determine combined fatigue strengths have considered only biaxial tension-compression stresses. These biaxial tension - compression stresses in most cases have been produced by subjecting a solid round specimen to combined torsional and bending moments. By means of combined torsion and bending, ratios of the biaxial principal stresses $\frac{\sigma_2}{\sigma_1}$ from -1.0 to 0 can be investigated. A wider range of biaxial stress conditions can be investigated by subjecting a thin-walled tubular specimen to fluctuating internal pressure combined with fluctuating axial tension or compression. A thin-walled tubular specimen in which the stresses are essentially uniform throughout the cross-section has the added advantages that size effects are reduced and possible strengthening effects of lower stressed fibers are eliminated. For the foregoing reasons this investigation on biaxial tension-tension and biaxial tension-compression fatigue strengths of aluminum alloy 14S-T4 was conducted.

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13–18, 1954.

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[2] Head, Department of Engineering Mechanics, The Pennsylvania State University, State College, Pa.

[3] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 765.

BIAXIAL FATIGUE TESTS OF ALUMINUM ALLOY 14S-T4

The results reported in this paper represent a continuation of an investigation sponsored by the National Advisory Committee for Aeronautics and reported in reference (**9**). The present paper gives a reinterpretation of the results previously reported and presents new test results for combined tension-compression fatigue stresses. The authors found only one reference where both tension-tension and tension - compression fatigue strengths have been previously investigated (**12**).

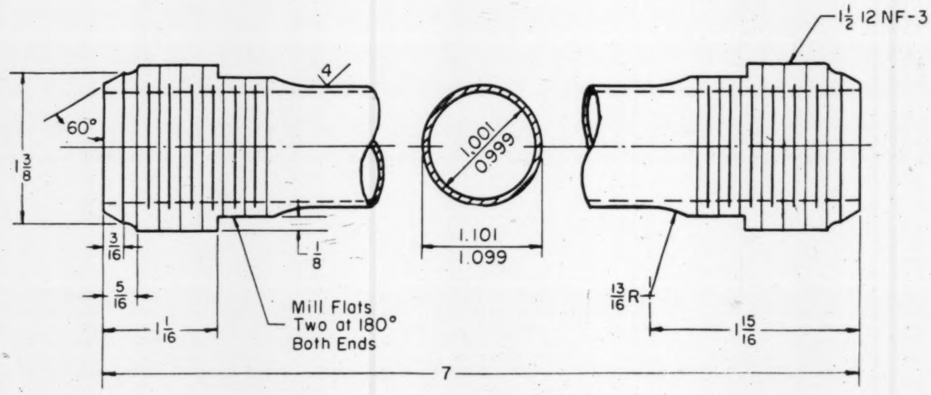

FIG. 1.—Biaxial Fatigue Specimen.

NOTES.—Fractional Dimensions Held to ±1/64. Inner and Outer Surface of Tube Polished Axially.

Material and Specimens:

The material tested in this investigation was a heat-treated aluminum alloy designated 14S-T4. It was received in the form of hot-rolled bars $7\frac{1}{4}$ in. long and $1\frac{5}{8}$ in. outside diameter with a bore of $\frac{11}{16}$ in.

The nominal composition in addition to aluminum and normal impurities was as follows: copper, 4.4 per cent; silicon, 0.8 per cent; manganese, 0.8 per cent; and magnesium, 0.4 per cent.

The mechanical properties as furnished by the Aluminum Company of America were: tensile strength, 61,500 psi ± 2.8 per cent; yield strength, 36,000 psi ± 10.4 per cent; and elongation in four diameters, 21.4 per cent ± 4.5 per cent. The above values are the average of tests on specimens taken from the bars in longitudinal, transverse, and diagonal directions. The manufacturers' data indicated that about half the variation in the mechanical properties could be attributed to anisotropy, while the remaining difference was due to normal variations in the material.

Static tests on finished tubular specimens yielded the following average values: tensile strength, 63,000 psi; yield strength (0.2 per cent offset), 37,500 psi; elongation in 2 in., 21.5 per cent; modulus of elasticity, 10.8×10^6 psi.

The finished specimens had an overall length of 7 in. The test section length was approximately 4 in. with an inside diameter of 1 in. and a wall thickness of 0.05 in. Both the inner and outer surfaces were polished with 9/0 metallurgical abrasive paper in order to minimize the possibility of fatigue cracks starting at surface imperfections

Complete dimensions and tolerances of the specimen are shown in Fig. 1.

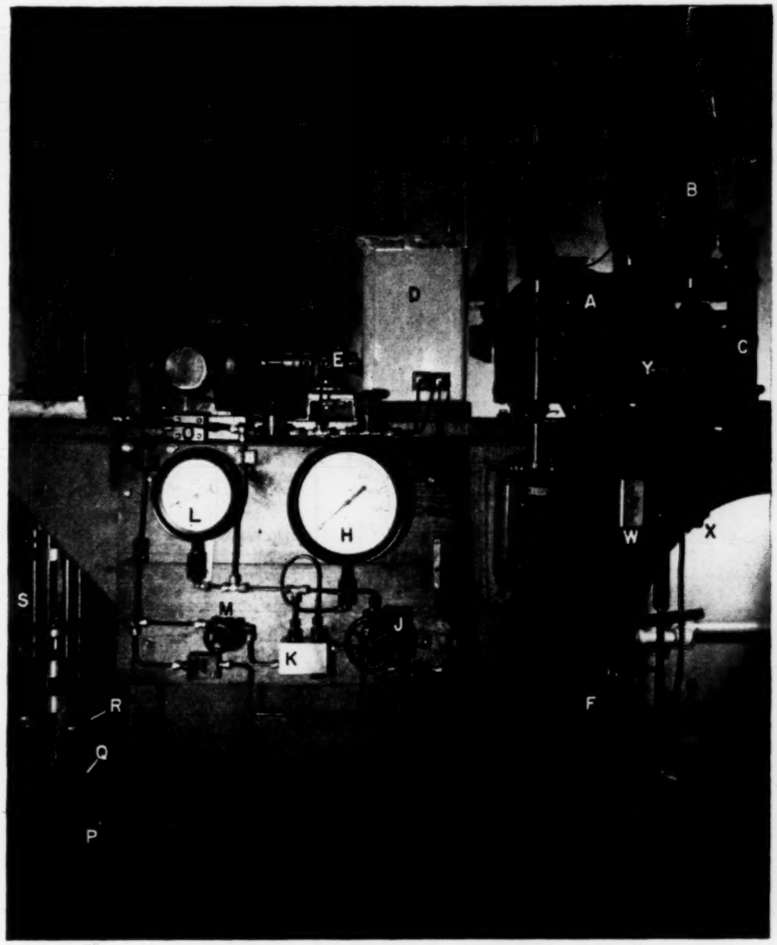

FIG. 2.—Biaxial Fatigue Machine, Front View.

Stresses Produced:

For a tubular specimen subjected to an axial load P and internal pressure p, the axial stress is

$$\sigma_1 = \frac{P + \pi p a^2}{\pi(b^2 - a^2)} \quad \text{..........} \quad (1)$$

where:

a = the inner radius of the specimen, and

b = the outer radius.

The circumferential stress, σ_2, for a thick-walled cylinder, by Lamés theory, can be shown to be:

$$\sigma_2 = \frac{p(a^2 + b^2)}{(b^2 - a^2)} \quad \text{...........} \quad (2)$$

The maximum stress defined by Eq 2 occurs on the inner surface of the specimen. Using the assumption of a thin-walled cylinder, the average circumferential stress is about 5 per cent less than the value given by Eq 2 (for the average specimen dimensions used).

For fluctuating loads which vary from minimum values of p''' and P''' to maximum values of p' and P' (with mean values $p'' = \frac{(p' + p''')}{2}$ and $P'' = \frac{(P' + P''')}{2}$ the maximum, mean, and minimum stress values are

$$\sigma_1' = \frac{P' + \pi p' a^2}{\pi(b^2 - a^2)}, \qquad \sigma_1'' = \frac{P'' + \pi p'' a^2}{\pi(b^2 - a^2)},$$

$$\sigma_t''' = \frac{P''' + \pi p''' a^2}{\pi(b^2 - a^2)} \quad ..(3)$$

$$\sigma_2' = \frac{p'(a^2 + b^2)}{(b^2 - a^2)}, \qquad \sigma_2'' = \frac{p''(a^2 + b^2)}{(b^2 - a^2)},$$

$$\sigma_2''' = \frac{p'''(a^2 + b^2)}{(b^2 - a^2)} \quad ..(4)$$

Testing Machine:

The testing machine used for the biaxial tension-tension fatigue tests is described in detail in reference (9). In order to conduct the compression-tension tests reported herein, it was necessary to make modifications, the chief of which consisted in the construction of a compression adapter, to make possible the application of axial compression, and the development of an automatic pressure control system.

This specially designed testing machine is illustrated in Fig. 2. The power unit of the testing machine is a 3-hp, 1740-rpm, 220-v a-c motor, labeled *A* in Fig. 2, which actuates the eccentrics *Y* (Fig. 2) and *Z* (not shown in Fig. 2), through a 6 to 1 gear reduction. The eccentric *Y* operates an American Bosch injection pump *B* which supplies the fluctuating hydraulic pressure. The eccentric *Z* applies a force to the right end of the lever *P* through the bar *G*. The left end of the lever *P* is connected to the compression adapter *S*.

In order to fill the hydraulic system and obtain the minimum pressure, oil is drawn from the supply tank *D* by the hand pump *F* and pumped into the system through the check valve *N* (Fig. 2). This minimum pressure is indicated on the low pressure gage *L*. Before the machine can be started the the valve *J* must be closed in order to protect the low-pressure gage *L* from the high pressures developed by the pump *B*. This in effect separates the hydraulic system into two parts—a high-pressure side and a low pressure side, the only connection between the two being the check valve K_1 in the special valve block *K* (see Hydraulic Schematic, Fig. 3). After the machine is started, the maximum pressure is indicated on the high-pressure gage *H*. The check valve K_2 in the valve block *K* allows the maximum pressure to be measured but prevents the violent needle fluctuations which would be present if the gage were unprotected. During operation, loss of pressure is prevented by a Bristol hydraulic control *T* which is essentially a bourdon tube pressure gage wherein the pointer makes an electrical contact if it falls beneath or if it exceeds certain pressure levels. These pressure levels may be set into the controller by hand. Thus when the pressure in the low side of the hydraulic system falls below the minimum the controller makes contact and by means of a relay *U* (Fig. 4) causes the pump *E* to force oil into the low side of the system through the check valve *O*. The low side pressure is then higher than the minimum pressure in the high side, and oil will flow through the check valve K_1 into the high side when the pump is at the bottom of its stroke. The minimum pressure is therefore kept at a constant level which in turn maintains the maximum pressure at a constant level also as long as the stroke of the pump does not change. When the pressure on the low side is restored to its desired value the pointer on the controller makes contact again and turns off the pump *E* by interrupting the pump motor circuit. The sensitivity of the pressure controller may be regulated by manipulation of the by-pass valve *I* which controls the amount of pump output actually entering the system through the check valve *O*. The by-pass valve is a very important component of the control system in that proper adjustment will prevent the make-up pump *E* from overshooting the desired minimum pressure as it forces oil into the hydraulic system.

After a fatigue crack occurs in the specimen, oil is forced through the crack against a sheet aluminum shield and is thus directed downward into the balanced pan *R* (Fig. 2). The oil in the pan causes an unbalance which trips the microswitch *Q* and shuts off the machine. The number of stress cycles which the specimen has undergone may then be read from the revolution counter *C*.

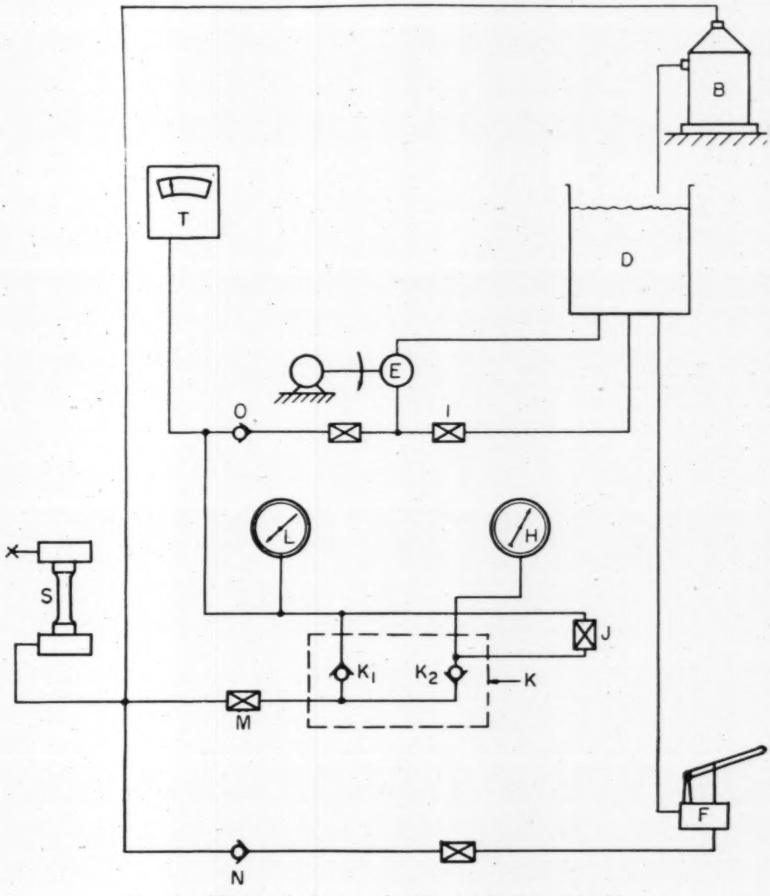

FIG. 3.—Hydraulic System for Biaxial Fatigue Machine.

In order to prevent the make-up

pump from continuing to operate after the development of a fatigue crack in the specimen, it was necessary to connect the electrical system in such a manner as to permit the microswitch to interrupt both the 220-v loading motor circuit *A* and the 110-v pressure control system. This was accomplished without the use of additional relays by using one line of the 220-v supply system and the neutral line of the 110-v supply system as the 110-v source for the pressure control system (see Electrical Schematic, Fig. 4). Therefore, when the microswitch turns off the motor *A* it also interrupts the pressure control circuit. The switch *W* allows the microswitch to be by-passed if desired. This is sometimes necessary when making initial adjustments at the beginning of a test run in order to prevent accidental tripping of the microswitch from stopping the machine.

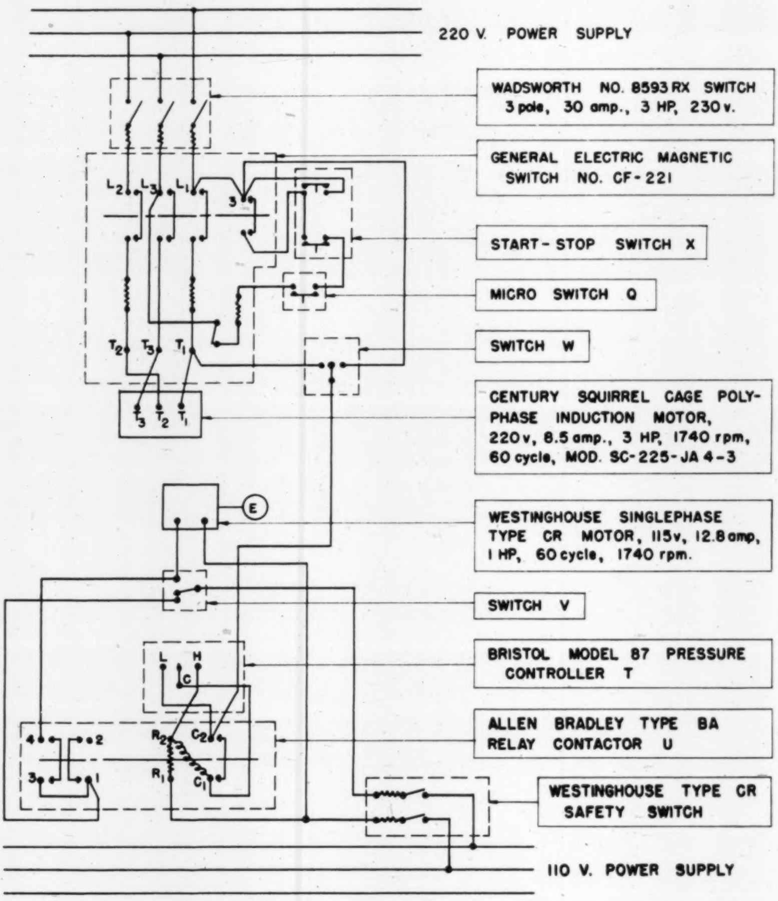
220 V. POWER SUPPLY
WADSWORTH NO. 8593 RX SWITCH 3 pole, 30 amp., 3 HP, 230 v.
GENERAL ELECTRIC MAGNETIC SWITCH NO. CF-221
START-STOP SWITCH X
MICRO SWITCH Q
SWITCH W
CENTURY SQUIRREL CAGE POLYPHASE INDUCTION MOTOR, 220 v, 8.5 amp., 3 HP, 1740 rpm, 60 cycle, MOD. SC-225-JA 4-3
WESTINGHOUSE SINGLEPHASE TYPE CR MOTOR, 115v, 12.8 amp, 1 HP, 60 cycle, 1740 rpm.
SWITCH V
BRISTOL MODEL 87 PRESSURE CONTROLLER T
ALLEN BRADLEY TYPE BA RELAY CONTACTOR U
WESTINGHOUSE TYPE CR SAFETY SWITCH
110 V. POWER SUPPLY
L2
L3
L1
3
T2
T3
T1
T3
T2
T1
E
L
H
C
4
2
3
1
R2
C2
R1
C1

FIG. 4.—Electrical System for Biaxial Fatigue Machine.

Before it was possible to conduct tests at stress ratios $\frac{\sigma_2}{\sigma_1}$ of infinity and -1, it was necessary to design and construct a compression adapter *S*, Fig. 5 to convert the axial tensile load from the lever *P* into axial compression. The compression adapter is connected to the machine by means of threaded fittings in the upper receiving plate *S*-8 and lower receiving plate *S*-1. The upper receiving plate is connected to the lower transfer plate *S*-2 by four tension rods *S*-9, and the lower receiving plate is connected to the upper transfer plate *S*-7 in the same manner. The tensile load on the receiving plates is therefore converted to compression at the transfer plates and is transmitted to the loading heads *S*-3 and *S*-6 by means of spherical seats. The upper loading head *S*-6 includes an hydraulic fitting *S*-11 which acts as a vent while the system is being filled with oil. The lower loading head is provided with an hydraulic fitting *S*-10 which is connected to the hydraulic system. The specimen *S*-5 is screwed into the upper loading head until the 60-deg male cone (Fig. 1) makes an oiltight junction with a mating female cone in the loading head. In order to maintain the necessary alignment between the loading heads to allow the tension rods to pass through, the specimen enters the lower loading head by means of the locking ring *S*-4. This ring has right-hand internal threads to accommodate the specimen and left-hand external threads which engage left-hand internal threads in the lower loading head. It is therefore possible to advance the specimen into the lower loading head by turning only the locking ring until the conical seats effect an oiltight seal. A special spacer was made of 1-in. pipe between nuts on the tension rods *S*-9. Each rod was inserted in the spacer and the nuts tightened to the same torque in each case. The nuts and rods were then drilled for cotter pins while the rod remained in the spacer. The rods and nuts were then stamped with identification numbers so that the nuts would always be in their proper positions on the rods when the compression adapter was assembled, therefore minimizing the possibility of nonaxial loading.

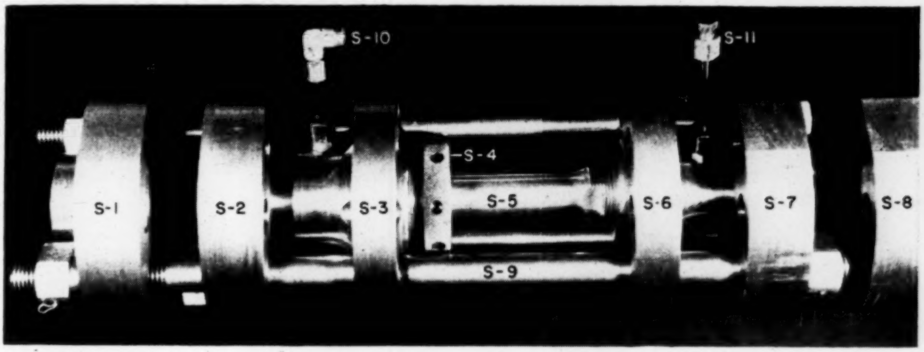

FIG. 5.—Compression Adapter.

Calibration of Testing Machine:

The tension bar *G* was calibrated by subjecting it to tensile loads on a Baldwin-Southwark hydraulic testing machine and observing readings from two SR-4 electric strain gages placed on opposite sides of the bar. A calibration curve was plotted from these data, thus making it possible to set axial loads into the machine by measuring strains in the tension bar.

An investigation was made to determine the effect of neglecting inertia forces due to the motion of the lever *P*. The equipment used consisted of a Hathaway type S-14A oscillograph which made photographic records of the strains in the specimen while the drive shaft was rotated by hand, and then again, while the machine operated at normal speed. Comparisons of these records showed the maximum error due to neglecting inertia forces to be less than 1 per cent of the applied load.

Axiality of loading was checked by measuring strains at four points equally spaced around the circumference of the specimen. The strain variation over the cross-section of the specimens was held to an error of less than 2 per cent.

The pressure gages were calibrated by means of a dead weight gage tester. Pressure readings could be observed to the nearest 25 psi. This means that the errors in stresses due to errors in pressure values was about 125 psi or of negligible amount.

Method of Testing:

Before testing the wall thickness of each specimen at 16 locations was measured by a special apparatus (Fig. 6). consisting of a rigid bar *FF* mounted between two lathe tail stocks supported by a lathe bed. A 0.0001-in. dial indicator *KK*, also mounted on the lathe bed, is set to read zero when its pointer bears on the protrusion *LL*. The wall thickness of the specimen may be read directly on the dial when the specimen is placed over the protrusion. The outside diameter of the specimen is obtained by averaging micrometer readings taken in two perpendicular directions at each of four cross-sections along the specimen length.

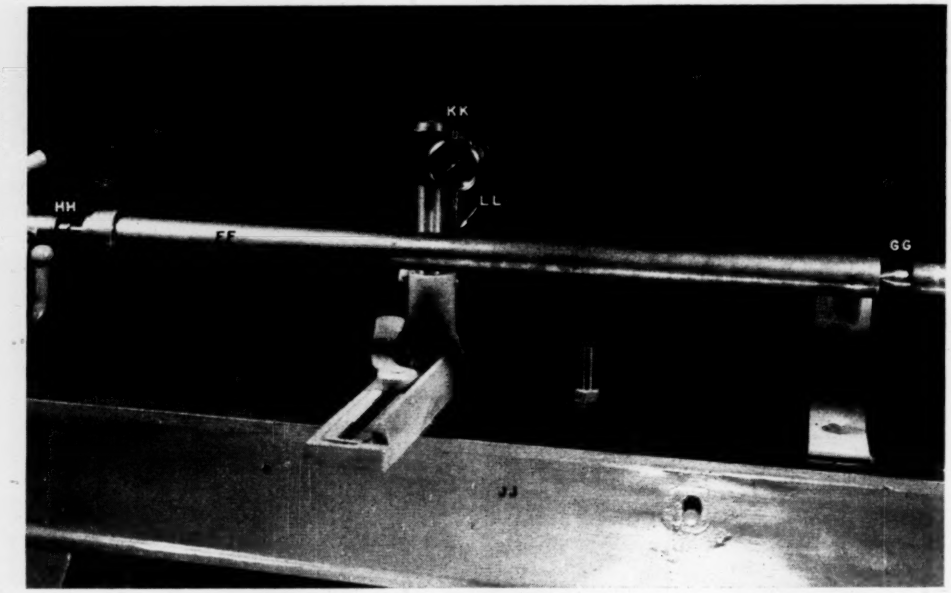

FIG. 6.—Wall Thickness Measuring Apparatus.

After the dimensions of the specimen

are obtained, it is mounted in the compression adapter (Fig. 5). The adapter is then attached to the testing machine by the upper and lower receiving plates *S*-1 and *S*-8 (Fig. 5). After internal pressure is applied, the specimen connections are checked for possible oil leakage.

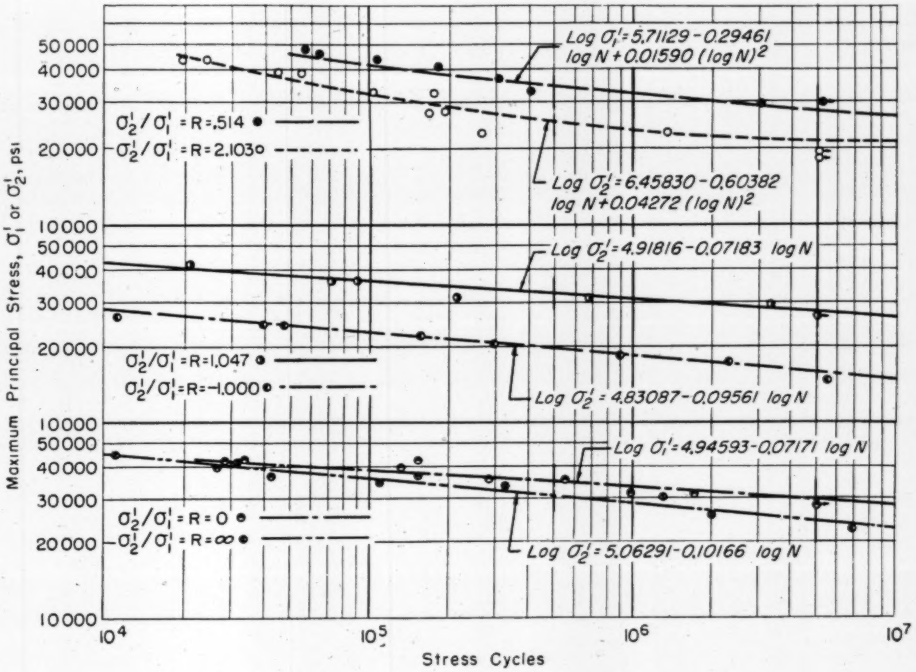

FIG. 7.—*S-N* Curves Plotted by Least Square Method.

The eccentric *Z* is next adjusted under static loading conditions to provide the desired minimum and maximum axial loads. The loads were measured by a calibrated electric strain gage type dynamometer.

The internal pressure in the specimen is adjusted by use of the eccentric *Y*. The hydraulic system is then filled by means of the hand pump *F* until the desired minimum pressure is attained with the pump at the bottom of its stroke. The maximum pressure is adjusted by the eccentric setting and by the load rack of the Bosch pump. The eccentric *Y* can be adjusted relative to the drive shaft in order to bring the maximum values of the internal pressure and axial load in phase. The foregoing phase adjustment is done manually and checked under dynamic loading conditions using SR-4 gages and a Hathaway oscillograph to record the axial and circumferential strains on the specimen. It is found that when the load is adjusted statically this in-phase condition is maintained under dynamic loading.

After the machine is in operation for a few minutes, slack in the mechanical linkages may require readjustment of loads. During subsequent operation the applied load values are checked several times a day. The microswitch shuts off the motor when a specimen fractures and the cycles to failure can then be obtained from the revolution counter reading.

Test Results:

Fatigue strengths were obtained in this investigation, for ratios of circumferential stress to axial stress $R = \frac{\sigma_2}{\sigma_1}$ equal to infinity and -1. These stress ratios correspond to states of stress $\sigma_2' = -\sigma_1'$ and $\sigma_1' = 0$. Tests were previously reported (9) for stress ratios $R = \frac{\sigma_2'}{\sigma_1'} = 0$, 0.5, 1.0, and 2.0. In all tests the minimum stress values were kept as small as possible and the values of these stresses may therefore be considered as equal to zero. This means that the ratio of the mean to maximum stresses was maintained approximately equal to 0.5.

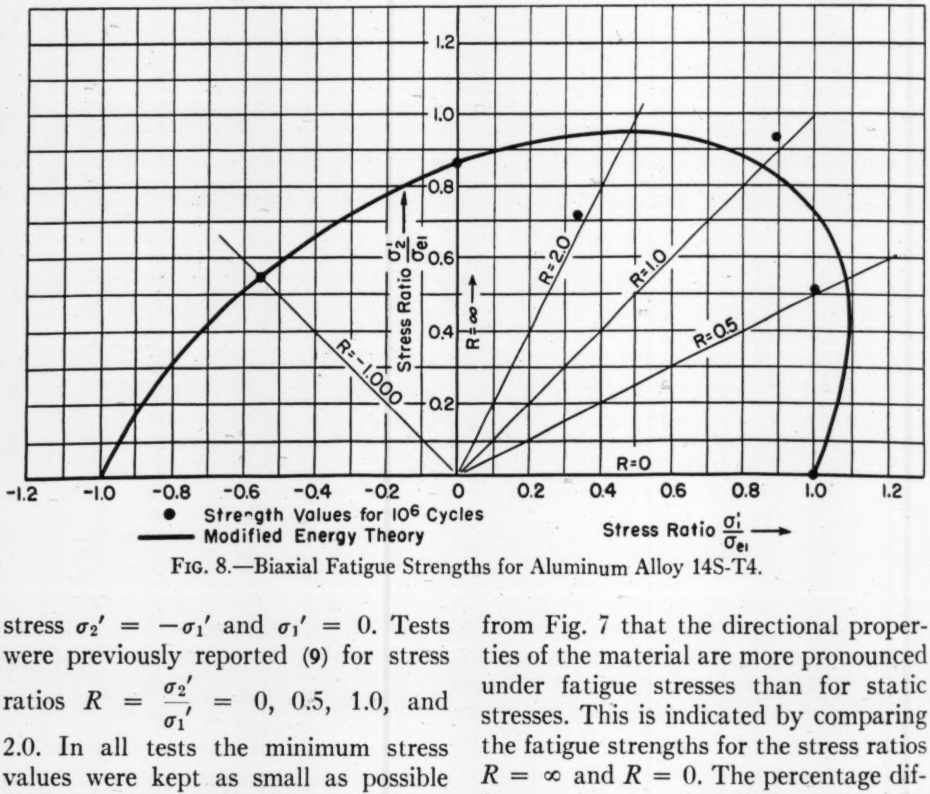

FIG. 8.—Biaxial Fatigue Strengths for Aluminum Alloy 14S-T4.

The *S-N* relations for each of the foregoing six stress ratios are plotted in Fig. 7. For each stress ratio, in Fig. 7, the equation of the curve which best fitted the test results was determined using the method of least squares. These equations are also shown in Fig. 7. Specimens which did not fail are indicated in Fig. 7 in the usual manner by means of arrows.

Analysis and Discussion:

Figure 7 shows influence of combined stress on the fatigue strength, since if a state of combined stresses had no influence on the test results all *S-N* diagrams would coincide. It is also clear from Fig. 7 that the directional properties of the material are more pronounced under fatigue stresses than for static stresses. This is indicated by comparing the fatigue strengths for the stress ratios $R = \infty$ and $R = 0$. The percentage differences between these fatigue strengths is about 15 per cent for 10^6 cycles, while the strength difference under static stress conditions is much less than this value.

The influence of the principal stress ratio R is shown by plotting the strength ratios $\frac{\sigma_1'}{\sigma_{e1}}$ *versus* $\frac{\sigma_2'}{\sigma_{e1}}$ (Fig. 8). In determining these ratios, strength values were selected from Fig. 7 for 10^6 cycles. The value of σ_{e1} used is the value of σ_1' for $\sigma_2' = 0$, that is, for a fluctuating axial stress σ_1 which varies from essentially zero to a value σ_1'.

Various theories were considered in an attempt to interpret the data shown in Fig. 8. The anisotropic nature of the material precludes the use of the various theories that have been proposed in the past, such as the shear, stress, and distortion energy theories. Anisotropic theories proposed by Findley (11) are also inadequate since these theories are intended for use in cases of combined tension and shear. A theory referred to as the modified energy theory was developed in an attempt to interpret the test results obtained. This theory provides for anisotropic effects and reduces to the fatigue distortion energy theory for isotropic materials (13). It can be shown[4] that for the state of stress considered the theoretical biaxial fatigue strength is defined by

$$(\sigma_1')^2 + k_1\sigma_1'\sigma_2' + (\sigma_2')^2 + k_3\sigma_2' = \sigma_{e1}^2 \ldots (5)$$

where:

σ_{e1} = the fatigue strength.

The constant k_3 in Eq 5 is determined from the test data by noting that for $\sigma_1' = 0, k_3 = \dfrac{\sigma_{e1}^2 - (\sigma_2')^2}{\sigma'_2}$ For evaluating k_1, the test results for $\sigma_1' = -\sigma_2'$ were used. Figure 8 shows a plot of the foregoing Modified Energy Theory.

A comparison of the theoretical and experimental results in Fig. 8 shows general agreement between theory and tests. There are not sufficient test data, however, to arrive at a definite conclusion. In examining the test results of Fig. 8, it appears that the value for $R = 2.0$ is inconsistent with the other results obtained.

CONCLUSIONS

Biaxial tension-tension and tension-compression fatigue strength values for an aluminum alloy 14S-T4 were obtained in this investigation showing the general influence of biaxial strength on fatigue strength. It was also found that the degree of anisotropy was greater for fatigue than for static stresses, the fatigue strength in the circumferential direction of the tubular specimens being about 85 per cent of that in the longitudinal direction.

Available theories of failure were found inadequate for interpretating the test data and for this reason a modified energy theory was proposed. The validity of this new theory could not be determined in view of the limited amount of test data available for the stress range considered.

Acknowledgment:

This paper describes a part of a Ph.D. thesis conducted by R. W. Bundy under the direction of Joseph Marin. The help of L. W. Hu and H. A. B. Wiseman in conducting this investigation is appreciated.

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[4] A paper is being prepared which gives the theoretical development of this theory.

REFERENCES

(1) H. J. Gough, and H. V. Pollard, "The Strength of Metals Under Combined Alternating Stresses," *Proceedings*, Inst. Mechanical Engineers, Vol. 131, p. 3 (1935).

(2) P. D. Narmore, "A Fatigue Study of Strong Steel Under Combined Alternating Stresses," Ph.D. Thesis, University of Michigan (1937).

(3) T. Nisihara, and M. Kawnmoto, "Fatigue Tests of Steel Under Combined Bending and Torsion," Society of Mechanical Engineers, Japan, Vol. 6, No. 24, August, 1940. English Translation No. 95, Caterpillar Tractor Co.

(4) J. A. Sauer, "A Study of Fatigue Phenomena Under Combined Stress," Proceedings of the 7th International Congress for Applied Mechanics, Vol. 4 (1948).

(5) J. Marin, "Strength of Steel Subjected to

Biaxial Fatigue Stresses," *The Welding Journal Research Supplement*, Vol. 21, p. 554 (1942).

(6) W. Sawert, "The Behavior of Steel Under Reversed Multi-Axial Stresses," *Zeitschrift des Vereines deutscher Ingeneiure* Vol. 87, October 2, 1943, pp. 609–615.

(7) G. K. Morikawa, and L. Griffis, "The Biaxial Fatigue Strength of Low Carbon Steels," *The Welding Journal Research Supplement*, Vol. 24, p. 167 (1945).

(8) H. J. Gough, *et al.*, "Some Experiments on the Resistance of Metals to Fatigue Under Combined Stresses," York House, London (1951).

(9) J. Marin, and W. P. Hughes, "Fatigue Strengths of 14S-T4 Aluminum Alloy Subjected to Biaxial Tensile Stresses," *Technical Note 2704*, National Advisory Committee for Aeronautics, June, 1952.

(10) W. N. Findley, "Combined Stress Fatigue Strength of 76S-T61 Aluminum Alloy with Superimposed Mean Stresses and Corrections for Yielding," *Technical Note 2924*, National Advisory Committee for Aeronautics, May, 1953.

(11) W. N. Findley, "Fatigue of 76S-T61 Aluminum Alloy Under Combined Bending and Torsion," *Proceedings*, Am. Soc. Testing Mats., Vol. 52, p. 818 (1952).

(12) H. Majors, Jr., B. D. Mills, Jr., and C. W. MacGregor, "Fatigue Under Combined Pulsating Stresses," *Journal Applied Mechanics*, Vol. 15, Sept., 1949, pp. 269–276.

(13) J. Marin, "Engineering Materials," Prentice Hall Book Co., New York, N. Y., (1952).

DISCUSSION

Mr. Harry Majors, Jr.[1] (*presented in written form*).—The authors have presented a fine discussion of biaxial fatigue tests on thin-walled tubes and are to be complimented for obtaining data which is time-consuming. Figure 8 represents only six points, but much precedes the obtaining of this data.

A similar machine was used in 1949[2] in which the various stress ratios were obtained, using suitable pressure heads. These heads can give pure tension in longitudinal or tangential direction, tension-tension, tension-compression, or compression stresses.

Do the authors see any advantage in plotting $\frac{\sigma_1'}{\sigma_{e1}}$ *versus* $\frac{\sigma_2'}{\sigma_{e2}}$, where σ_{e1} is explained by the authors and σ_{e2} is the value of σ_2' for $\sigma_1' = 0$, that is, for a fluctuating stress σ_2 which varies from essentially zero to a value σ_2.

Does Fig. 8 imply that σ_{e1} in tension is equal to σ_{e1} in compression?

Would the authors comment further on the predominant direction of the polishing scratches?

When the material is markedly anisotropic, then the energy theory should be modified as suggested by the authors. This has been given increased attention in recent years as many strange metals come into engineering use, especially those for use in atomic energy machines.

Another set of data for $R = 2.0$ would be interesting.

Mr. R. E. Peterson.[3]—Would the authors comment on the directions of the fractures and the appearance of the fractures? With isotropic material, one could speculate rather reasonably as to what one would expect to get, but in the nonisotropic material, it seems to me this is not at all obvious; information regarding fracture directions would therefore add considerably to the value of the paper.

Mr. Louis F. Coffin, Jr.[4]—The authors have undertaken a very difficult but important investigation in the field of fatigue of metals and should be commended for their successful attack of the problem. As they point out, the experimental results obtained to date are rather meager, so that it is somewhat premature to draw very definite conclusions regarding the effect of combined stress. Additional experimental information will undoubtedly be forthcoming and is awaited with interest.

The anisotropy of the tubular specimens seems to be a problem encountered whenever tubes are machined from rolled bars. One way to resolve this problem is to fabricate the specimens from large billets. Utmost care must be used to ensure isotropy in the material if the effects of combined stress are to be properly investigated, since anisotropy can otherwise disguise the results.

The *S-N* curves for stress ratios $R = 0$ and $R = \infty$ (Fig. 7) are particularly interesting since they show a convergence at high stress levels. Here the anisotropy appears to be a function of stress level. The writer wonders whether an examination of the respective static tension tests in the low-strain regions might shed any light on this behavior. For example, if there were a difference in flow stress at very small plastic strains which disappeared at somewhat larger strains, the behavior illustrated in Fig. 7 might be explained. Hence, it would be of interest to see the static stress-strain curves in these two directions.

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[1] Research Professor, College of Engineering, University of Alabama, University, Ala.

[2] H. Major, Jr., B. D. Mills, Jr., and C. W. MacGregor, "Fatigue Under Combined Pulsating Stresses," *Journal Applied Mechanics*, Vol. 15, Sept., 1949, p. 269.

[3] Manager, Mechanics Division, Westinghouse Research Laboratories, East Pittsburgh, Pa.

[4] Supervisor, Mechanical Metallurgy, Knolls Atomic Power Laboratory, Schenectady, N. Y. (operated for the U. S. Atomic Energy Commission by the General Electric Co.).

MESSRS. R. W. BUNDY AND J. MARIN (*authors' closure*).—In reply to Mr. Majors' first question, the authors believe it is preferable to plot $\frac{\sigma_1'}{\sigma_{e1}}$ *versus* $\frac{\sigma_2'}{\sigma_{e1}}$ (as shown in Fig. 8) rather than $\frac{\sigma_1'}{\sigma_{e1}}$ *versus* $\frac{\sigma_2'}{\sigma_{e2}}$ because the use of σ_{e1} in both ratios reduces both coordinates to a common denominator and more clearly shows the effect of anisotropy on the fatigue strength of the material as the stress ratio, R, is varied.

Since no test data concerning σ_{e1} in compression were available, one of the basic assumptions of the modified energy theory, as presented here, is that σ_{e1} is the same in tension and compression. As a result of this assumption the curve representing the theory passes through both -1 and $+1$ on the $\frac{\sigma_1'}{\sigma_{e1}}$ axis of Fig. 8. This is not intended, however, to imply that σ_{e1} in tension and σ_{e1} in compression are equal for the material upon which the tests were conducted. In cases where test data show that σ_{e1} in compression differs from σ_{e1} in tension, the modified energy theory may be adjusted by the addition of a term which contains a constant that may be evaluated from the experimental value of σ_{e1} in compression.

The predominant direction of the polishing scratches was along the longitudinal axis of the specimen since the final polish was in this direction.

The authors agree that another set of data for $R = 2$ would be of considerable value. Unfortunately, however, there was not sufficient material available from which to make additional specimens.

Regarding Mr. Peterson's remarks, the directions of the fractures varied according to the value of the stress ratio, R. For a value of $R = 0$ (axial stress only) the specimens broke into two pieces with the direction of the fracture perpendicular to the longitudinal axis of the specimen. The specimens which were tested at a stress ratio of $R = 0.5$ exhibited the same type of failure as those tested in axial tension, except in some cases the direction deviated about five or ten degrees from perpendicular to the longitudinal axis. For all other stress ratios ($R = 1, 2, \infty, -1$) the fractures appeared as small cracks parallel to the longitudinal axis of the specimens. It is interesting to note that the specimens tested at a stress ratio of $R = 1$ failed by an axial crack rather than by a crack at 45 deg to the longitudinal axis as might have been expected if the material had been isotropic. However, since the specimens were stronger axially than circumferentially, the crack direction correlates with the anisotropy of the material.

Mr. Coffin's suggestion that an examination of the low strain regions of the static stress-strain curves in the axial and transverse directions might yield some information that would help explain the apparent dependence of anisotropy on stress level is an excellent one and is appreciated by the authors. Unfortunately, however, the static control data was primarily supplied by the manufacturer of the test material several years before the final fatigue tests were completed, and the original curves are not available for examination.

DYNAMIC CREEP AND RUPTURE PROPERTIES OF AN ALUMINUM ALLOY UNDER AXIAL STATIC AND FATIGUE STRESS*

By F. W. DeMoney[1] and B. J. Lazan[1]

Synopsis

Fatigue, stress-rupture, and creep data obtained under various combinations of mean and alternating axial stress are presented and discussed for rolled aluminum alloy 24S-T4 at 300 and 500 F. The data are presented as *S-N* curves and stress-range diagrams to show the effect of temperature, alternating-to-mean load ratio, and stress magnitude on the fatigue, stress-rupture, and creep properties.

The effect of temperature and alternating-to-mean load ratio on the characteristics of the creep curve is discussed on the basis of static and dynamic types.

The rôle of both creep and fatigue as factors in rupture is discussed with particular reference to temperature and alternating-to-mean load ratio.

Aluminum alloys are widely used for structures where fatigue is a design factor. In view of recent trends in service requirements, it becomes desirable to extend existing data so as to include elevated temperatures. Therefore, not only fatigue strength but also creep and rupture properties under various combinations of fatigue stress (or dynamic stress) and static stress become important.

Investigations involving these considerations made prior to 1949 are reviewed in reference (**1**).[2] Data are also available on temperature-resistant materials (**1, 2, 3**), SAE 4340 (**4**), and aluminum alloy 14S-T (**5**), in most cases for only a limited range of stress combinations. The room temperature properties of both rolled and extruded 14S-T6, 24S-T4, and 75S-T6 aluminum alloy for various combinations of reversed and static stress have been reported (**6**). The results of these and other investigations indicate that both creep and fatigue must be considered as factors which lead to failure and that the dominant factor is a function of stress range, type of material, and temperature.

In general, a rather limited number of combinations of alternating and static stress were investigated in prior work. Thus, it is difficult at present to generalize regarding the relative importance of creep and fatigue as causes of failure. The test program undertaken was intended to further understanding in this matter, with special reference to 24S-T4 aluminum.

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13–18, 1954.

[1] Research Fellow and Professor and Head, respectively, Department of Mechanics and Materials, University of Minnesota, Minneapolis, Minn.

[2] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 782.

TEST PROGRAM

In order to cover as uniformly as possible conditions ranging from static tension to reversed fatigue stress, selected steps of ratios A of alternating stress to mean stress were used rather than selected steps of mean stress. The alternating-to-mean load ratios A (**1**) selected for this work were: $A = 0$ (static tension), 0.15, 0.37, 0.89, 2.16, and ∞ (reversed stress). Tests were conducted at 300 and 500 F and stress magnitudes adjusted to cause failure in from 10^3 to 2×10^7 cycles (0.3 min to 100 hr). Both cycles to rupture and creep-time properties were determined under each of these conditions.

TEST MATERIAL AND SPECIMENS

Material:

The aluminum alloy used in this program was 24S-T4 (ASTM Designation: B 211 - 53 T, alloy CG21) in rolled rounds. The details on fabrication, metallographic structure, average chemical composition and room temperature properties are given in reference (**6**).

Specimen Type and Preparation:

The specimen used in this investigation consisted of a 1.75-in. straight section 0.4 in. in diameter with $1\frac{1}{8}$-in. fillets terminating in 1-in. diameter threaded ends. The effective gage length of this specimen was calculated to be approximately 2.15 in. as determined by the method outlined by Kinsey (**7**), using the Nadai-McVetty (**8**) relationship between stress and creep rate. The details of specimen preparation are given in reference (**6**).

TESTING EQUIPMENT AND TEST PROCEDURE

Testing Equipment:

The testing equipment used in this investigation included the axial stress machine, a temperature controller-recorder, and a creep recorder. The axial stress machine used in this project has been described in previous publications (**1, 2, 6**).

The equipment used to heat the specimen and maintain the test temperature within ±3 F has been described previously (**3**). The control couple, a 20-gage iron-constantan thermocouple, was inserted in a drilled hole in the specimen and the temperature at the test section was within ±1 F of the control couple.

Both static and dynamic creep were measured by motion of the lower end of the grip relative to the machine frame. A linearly variable differential transformer was used in most tests to measure this extension, the output of the transformer being continuously recorded. This system proved to be reliable, required little attention, and had a sensitivity of approximately 0.0005 in. with a reliability of about 0.001 in. Variations in expansion of grips and machine frame due to cycling of both room and furnace temperature after the test temperature was reached did not exceed 0.001 in.

Since most of the tests were of relatively short duration, the creep measuring accuracy indicated above is considered adequate.

Testing Procedure:

After the specimen had been at the test temperature for 1 hr, the following loading sequence was used. In tests under combined static and dynamic stresses (those with ratios $A = 0.15$, 0.37, 0.89, and 2.16) the static or mean stress component was applied first at a load rate of about 8000 psi per min for stresses less than 35,000 psi and of about 20,000 psi per min for stresses greater than 35,000 psi. The alternating or dynamic force was applied after a pause of 1 min under the static load. This force was applied gradually to prevent impact load conditions by gradually increasing the motor speed which required about seven seconds.

In the static tests ($A = 0$) only the preload was applied, and in the reversed stress tests ($A = \infty$) only the dynamic load was applied. The extension of the specimen was measured at all times during these loading cycles using the equipment described above. In reporting the data and plotting the creep curves, zero time and zero extension are defined as the moment immediately prior to starting the loading cycle (specimen at test temperature) with the specimen at zero stress. Time to failure however is defined from the instant full load (static plus alternating) is reached. These definitions are shown schematically in Fig. 1.

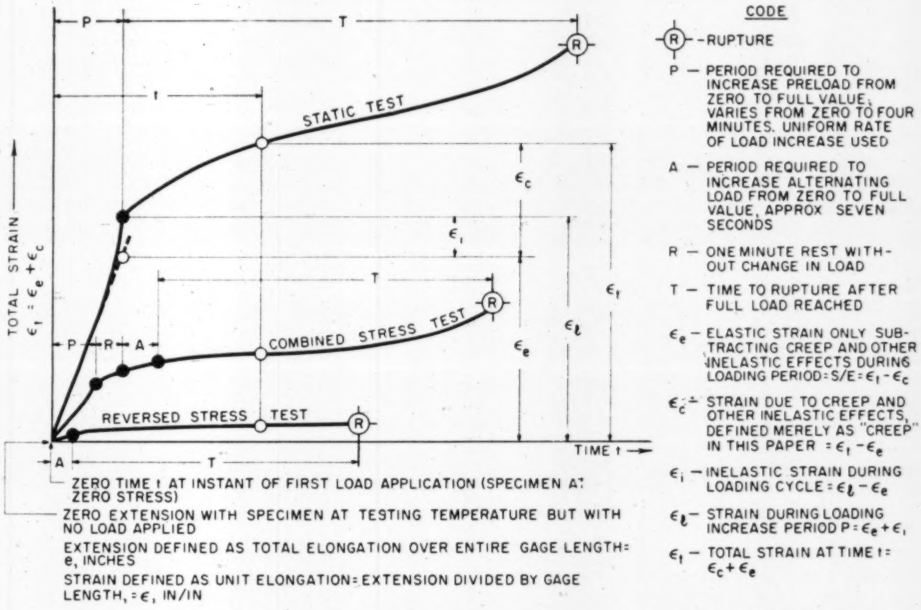
P
T
R
t
STATIC TEST
CODE
R - RUPTURE
P — PERIOD REQUIRED TO INCREASE PRELOAD FROM ZERO TO FULL VALUE, VARIES FROM ZERO TO FOUR MINUTES. UNIFORM RATE OF LOAD INCREASE USED
A — PERIOD REQUIRED TO INCREASE ALTERNATING LOAD FROM ZERO TO FULL VALUE, APPROX SEVEN SECONDS
R — ONE MINUTE REST WITHOUT CHANGE IN LOAD
T — TIME TO RUPTURE AFTER FULL LOAD REACHED
ε_e — ELASTIC STRAIN ONLY SUBTRACTING CREEP AND OTHER INELASTIC EFFECTS DURING LOADING PERIOD = S/E = ε_t − ε_c
ε_c ≐ STRAIN DUE TO CREEP AND OTHER INELASTIC EFFECTS, DEFINED MERELY AS "CREEP" IN THIS PAPER = ε_t − ε_e
ε_i — INELASTIC STRAIN DURING LOADING CYCLE = ε_l − ε_e
ε_l — STRAIN DURING LOADING INCREASE PERIOD P = ε_e + ε_i
ε_t — TOTAL STRAIN AT TIME t = ε_c + ε_e
ε_c
ε_i
ε_t
ε_l
ε_e
TOTAL STRAIN ε_t = ε_e + ε_c
T
R
COMBINED STRESS TEST
P R A
REVERSED STRESS TEST
R
TIME t
A
T
ZERO TIME t AT INSTANT OF FIRST LOAD APPLICATION (SPECIMEN AT ZERO STRESS)
ZERO EXTENSION WITH SPECIMEN AT TESTING TEMPERATURE BUT WITH NO LOAD APPLIED
EXTENSION DEFINED AS TOTAL ELONGATION OVER ENTIRE GAGE LENGTH = e, INCHES
STRAIN DEFINED AS UNIT ELONGATION = EXTENSION DIVIDED BY GAGE LENGTH, = ε, IN/IN

FIG. 1.—Schematic Diagram for Defining Time and Extension Terms and Symbols.

RESULTS AND DISCUSSION

Fatigue and Stress-Rupture Properties:

The fatigue and stress-rupture diagrams shown in Figs. 2 and 3 are plotted on the basis of the logarithm of the maximum or crest stress during the stress cycle *versus* the logarithm of the number of cycles and hours to failure, one stress *versus* number of cycles curve (or S-N curve) being plotted for each ratio A. The curve for ratio $A = 0$ is of course the stress-rupture curve under static stress.

From these figures it is seen that the S-N curves have different forms depending on the temperature and ratio A. The slope of the 300 F curves shown in Fig. 2 tend to increase with increasing ratio A. At some of the ratios, particularly $A = 0.37$, a rather well defined knee occurs beyond which the slopes gradually decrease. All 300 F curves show lower maximum stress with increasing ratio A, due probably to the more dominant rôle of fatigue as compared to creep as a cause of rupture.

The character of the 500 F S-N diagrams shown in Fig. 3 is pronouncedly different from the 300 F data discussed above. Curves for all ratios A are quite

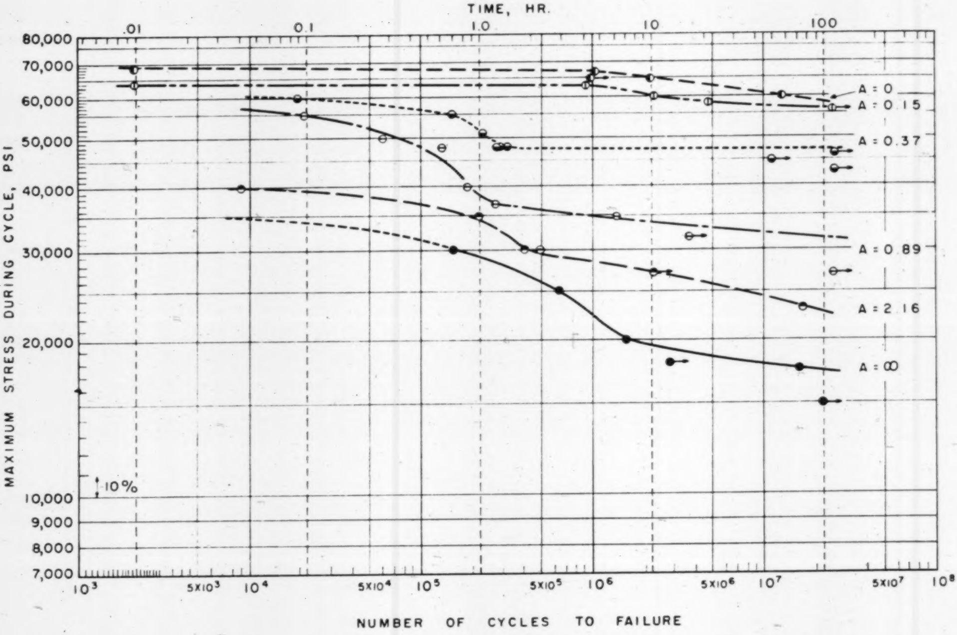

FIG. 2.—*S-N* Fatigue Diagrams at Various Ratios *A* for Rolled Aluminum Alloy 24S-T4 at 300 F.

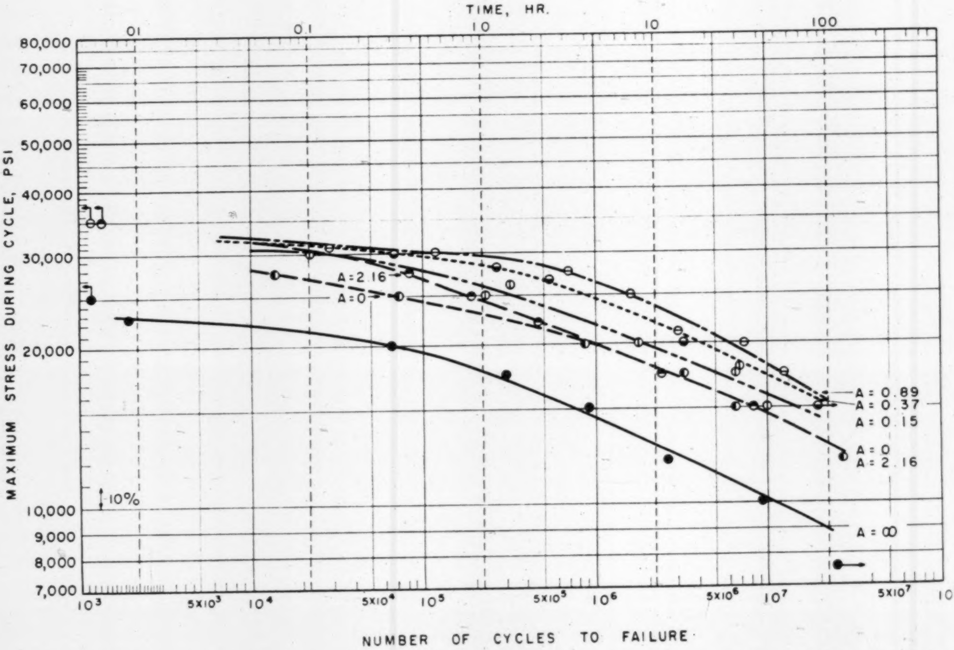

FIG. 3.—*S-N* Fatigue Diagrams at Various Ratios *A* for Rolled Aluminum Alloy 24S-T4 at 500 F.

similar in shape and display a gradually increasing slope with increasing number of cycles. Furthermore, the curves are more closely grouped than the 300 F curves. The order of the S-N curves is different than that at 300 F; as can be seen from Fig. 3, the highest S-N curve is at $A = 0.89$, whereas the lowest is at $A = \infty$. In general, it appears that at 500-F creep effect predominates as a cause of rupture, whereas at 300 F fatigue is the primary factor. These observations shall be discussed in greater detail later. The general decrease in the 500-F stress levels from the 300-F stress levels can be partially explained by the over aging (thus softening) effect the higher temperature has on this precipitation hardening alloy.

The fatigue data diagrammed in Figs. 2 and 3 are replotted on a stress-range basis in Fig. 4. The ordinate indicates the alternating stress and the abscissa the mean stress. Each curve indicates the combinations of alternating and mean stress which result in failure in a definite number of cycles in the range from 10^4 to 10^7 cycles. The series of inclined lines which pass through zero indicate the ratio A used. Also shown in this diagram are two straight lines, BC and $B'C'$, to indicate the combination of alternating and mean stress whose total equals the approximate ultimate strength S_u (based on the stress-rupture curve at 0.1 hr life for $A = 0$ at the temperature investigated). Data from an investigation (6) of room-temperature properties conducted on the same batch of material[3] are shown as a dotted line for comparative purposes.

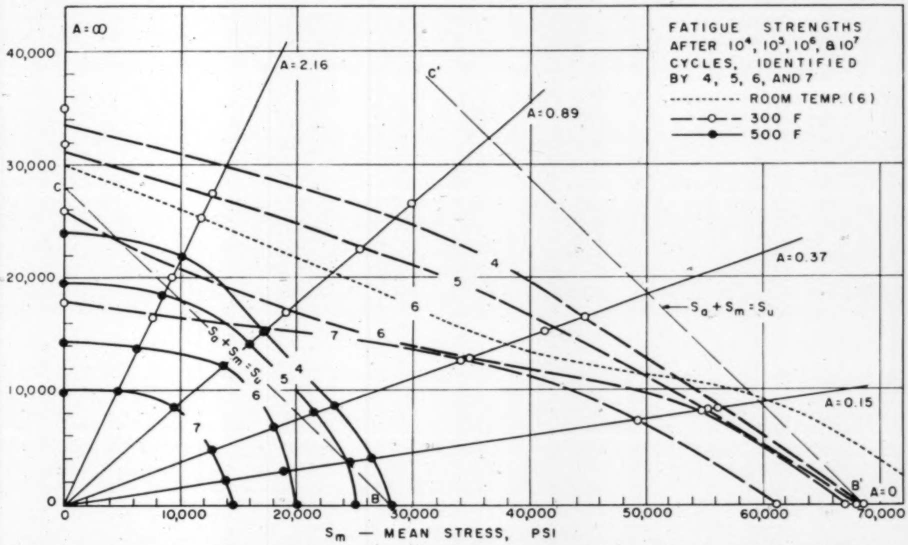

FIG. 4.—Stress-Range Fatigue Diagram for Rolled Aluminum Alloy 24S-T4 at 300 and 500 F.

At 300 F the curves approximate straight lines and from their slope it can be seen that the superposition of alternating stress greatly reduces the allowable mean stress at low ratios A. At 500 F the curves approximate arcs of circles, which resemble those determined in an investigation on temperature resistant materials (1, 2). Thus, alternating stress superimposed on mean stress at low ratios A reduces only slightly the allowable mean stress.

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[3] A single fillet-shaped specimen having higher tensile properties than the uniform test-section specimen (6) was used in this room temperature work.

It is desirable to determine if the stress-range relationship is sufficiently consistent for all ratios A to permit interpolation when only the reversed stress fatigue and static strengths are known. In order to establish such a relationship, the stress-range data of Fig. 4 are replotted on a completely unitless basis in Fig. 5 (in these unitless diagrams both the maximum ordinate and maximum abscissa are arbitrarily made equal to 1). Bands which include all curves for lives from 10^4 to 10^7 cycles are shaded to emphasize the difference between the 300 and 500 F data.

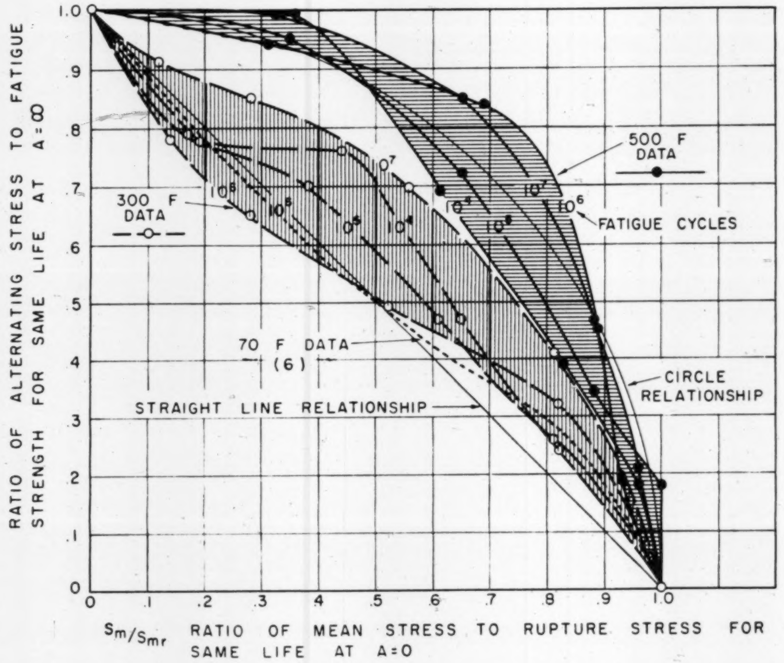

FIG. 5.—Stress-Range Bands for Rolled Aluminum Alloy 24S-T4 at 300 and 500 F Using Dimensionless Ratios.

The bands in Fig. 5 show trends similar to the curves shown in Fig. 4. The 300-F curves approximate a straight line, although there is some divergence on the safe side at the static end of the band, and the 500-F band approximates an arc of a circle. The effects of superimposing alternating stress on mean stress at low ratios A at the two temperatures can be compared in the following example. At 300 F increasing the alternating stress from 0 to 50 per cent of the fatigue strength reduces the allowable mean stress 35 per cent, while at 500 F the allowable mean stress is reduced only 15 per cent. Similar observations can be made with regard to the fatigue (upper left) end of the bands.

Creep Properties:

The total extension during each test (ϵ_t in Fig. 1 multiplied by the specimen gage length) is shown as a function of time in Figs. 6 and 7 on a log-log basis.

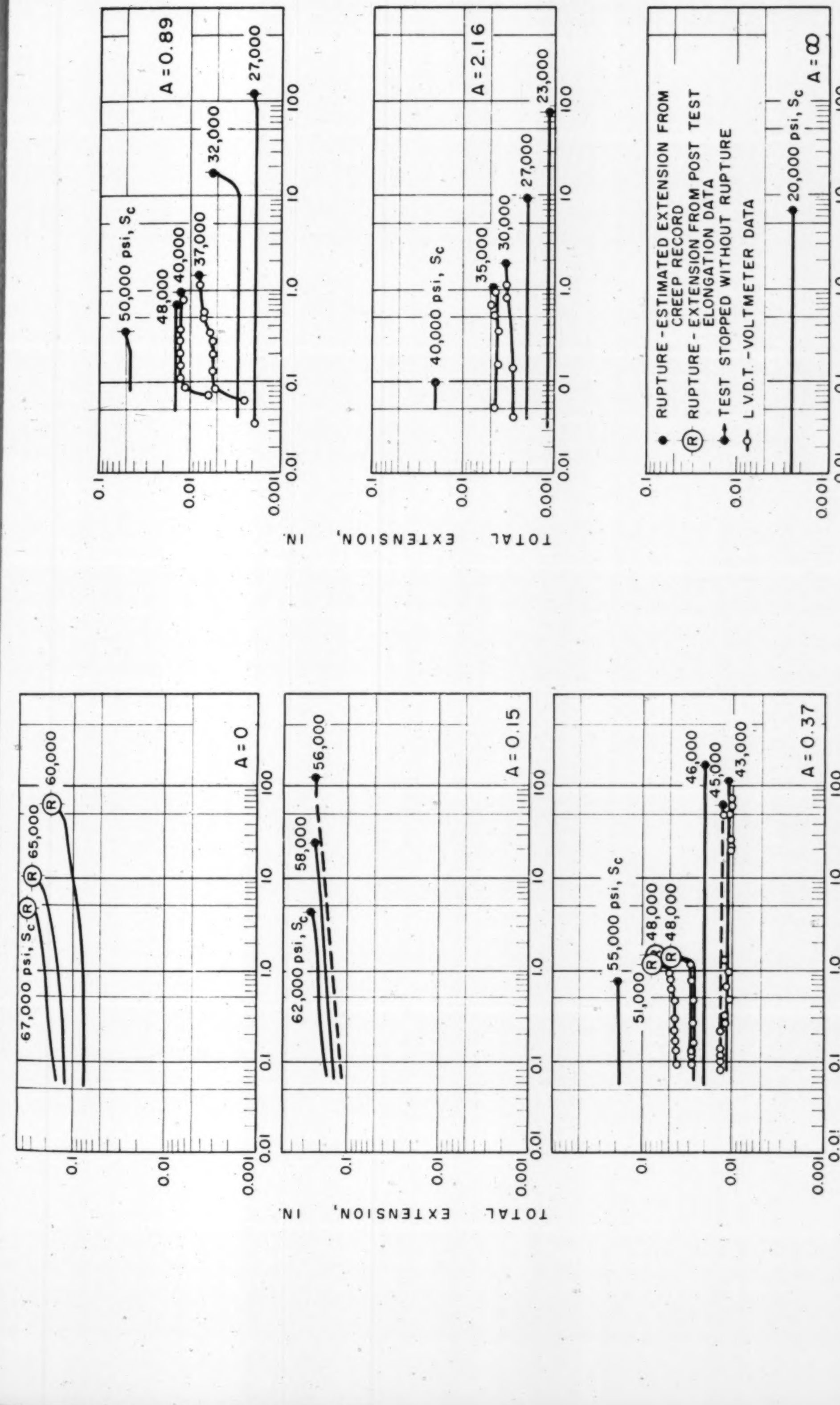

FIG. 6.—Total Extension Creep Curves for Rolled Aluminum Alloy 24S-T4 for Various Alternating-to-Mean Load Ratios *A* at 300 F.

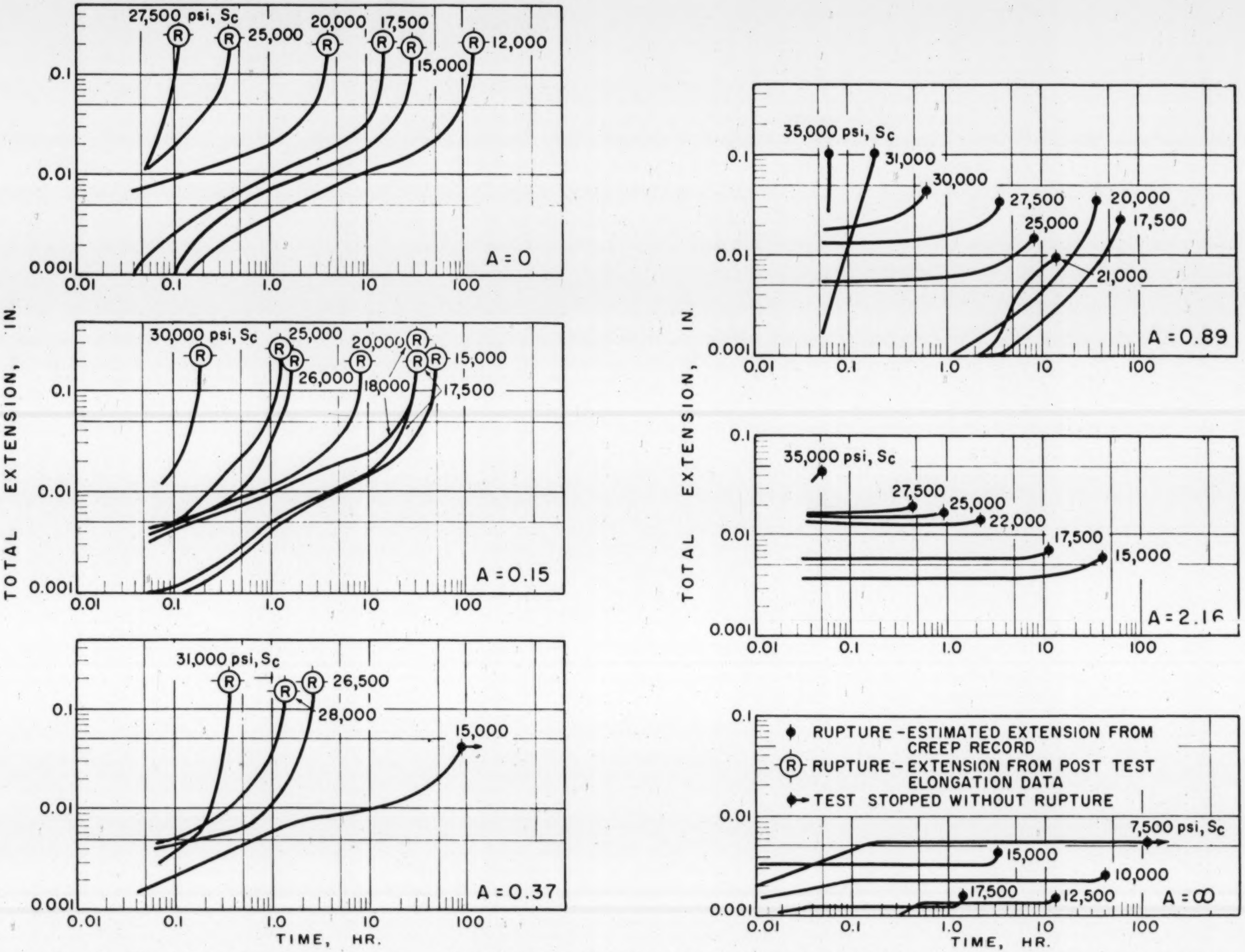

Fig. 7.—Total Extension Creep Curves for Rolled Aluminum Alloy 24S-T4 for Various Alternating to Mean Load Ratios *A* at 500 F.

Except where noted, all test data were obtained from the transformer-recorder approach described previously. The dashed lines in some of the curves indicate uncertainty due to abnormal scattering of the data.

It is seen from Fig. 6 that at 300 F large extension occurs only at the low ratios, $A = 0$ and 0.15. At the higher ratios A little creep occurs and the creep curves do not exhibit the usual second and third stage of creep prior to rupture. Under reversed stress ($A = \infty$) there appears to be no creep and the resultant curve is a straight line parallel to the abscissa. The creep curves at 500 F are shown in Fig. 7. In general, creep increases with increasing mean stress at all ratios A and decreases with increasing ratio A. Up to and including a ratio of 0.89 the curves are of the characteristic static type, but at 2.16 and ∞ the curves tend to be flat and display a low minimum creep rate even up to rupture. However, a few curves show a slight increase in creep rate just prior to rupture. This is in general agreement with the investigation on SAE 4340 (4).

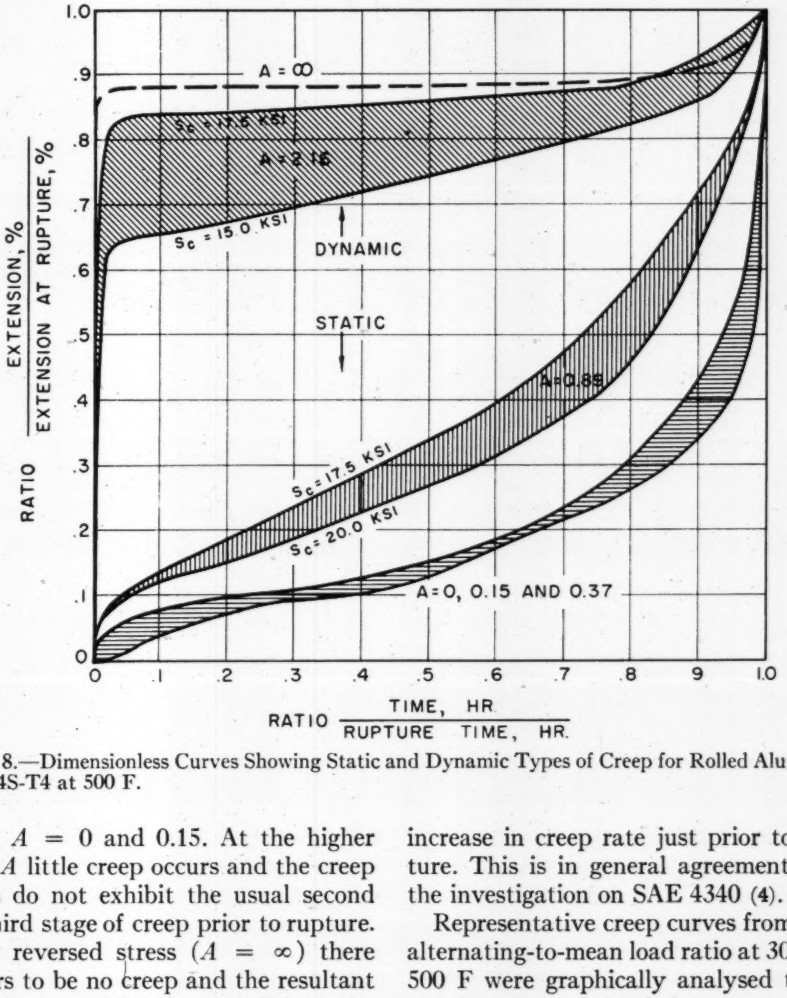

FIG. 8.—Dimensionless Curves Showing Static and Dynamic Types of Creep for Rolled Aluminum Alloy 24S-T4 at 500 F.

Representative creep curves from each alternating-to-mean load ratio at 300 and 500 F were graphically analysed to determine the nature of the creep curves. At both 300 and 500 F the creep curves were observed to fall into two types,

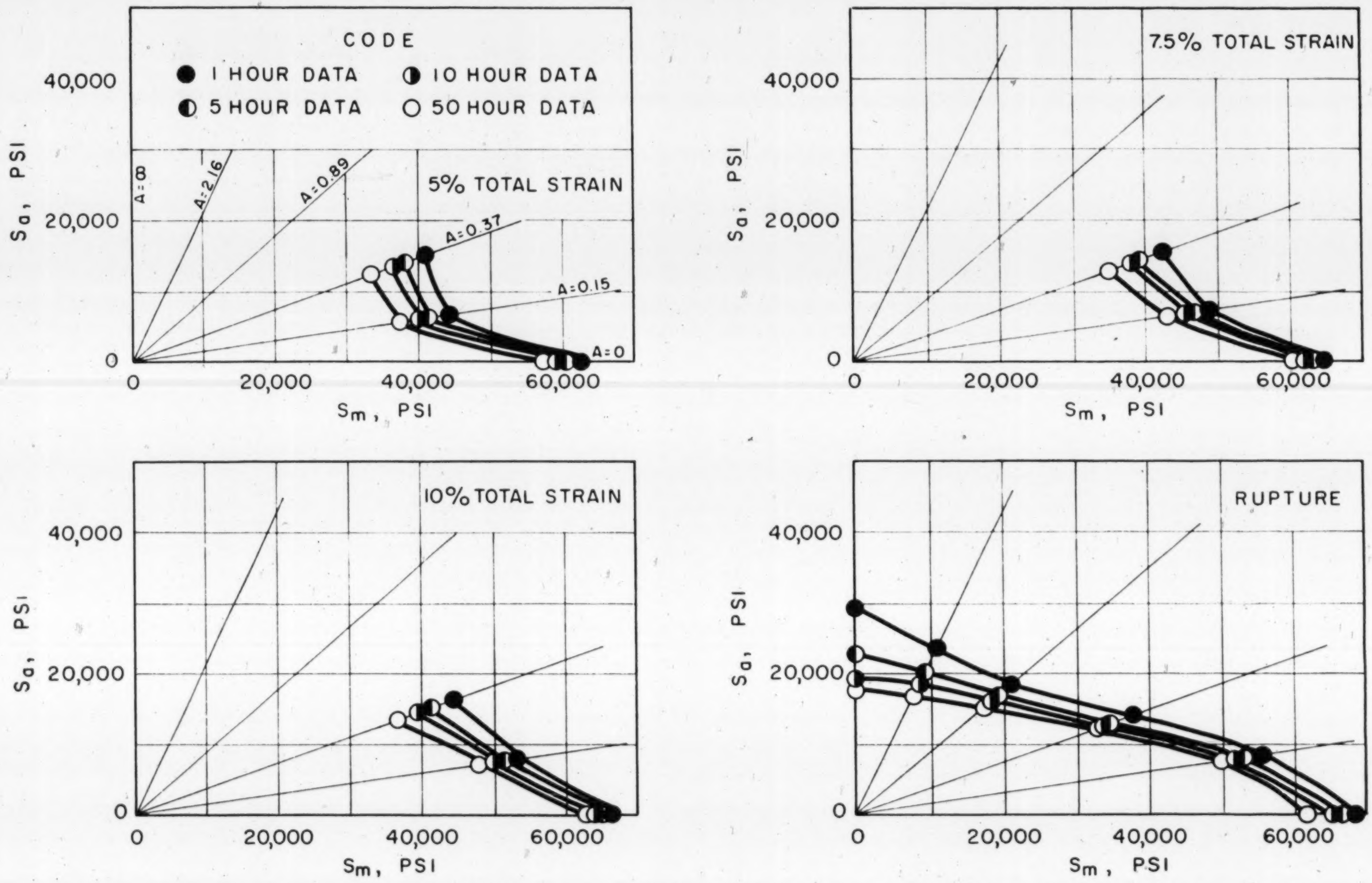

FIG. 9.—Stress Combinations for 5, 7.5, and 10 per cent Total Strain, ϵ_t, and Rupture of Rolled Aluminum Alloy 24S-T4 at 300 F.

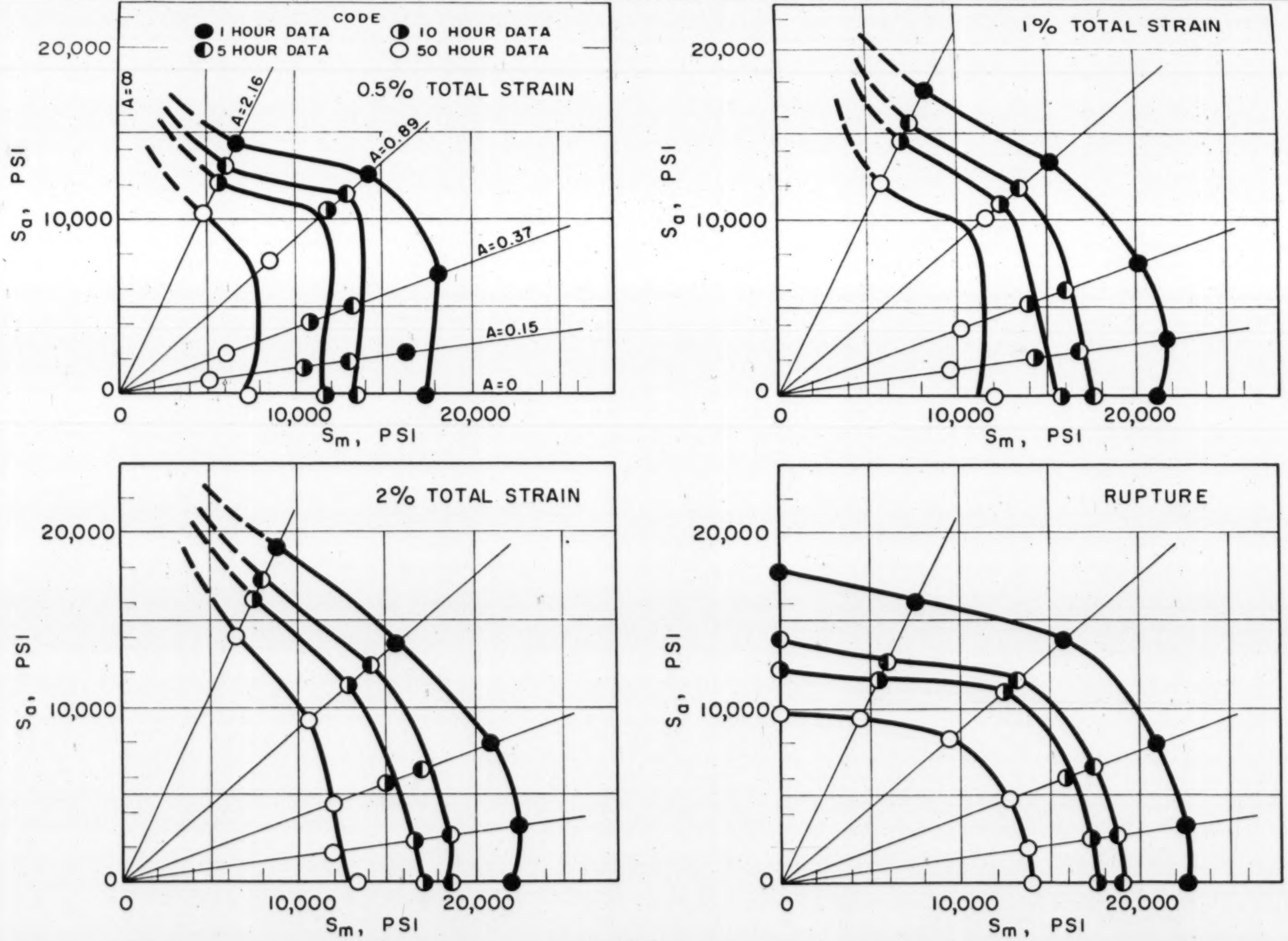

FIG. 10.—Stress Combinations for 0.5, 1, 2 per cent Total Strain, ϵ_t, and Rupture of Rolled Aluminum Alloy 24S-T4 at 500 F.

static and dynamic, although at 500 F the distinction between the two was more pronounced. For brevity, the analysis for 500 F only, Fig. 8, is shown. The static type creep curve, displayed at low alternating-to-mean load ratios, shows the customary three stages of creep, whereas a dynamic creep curve (high alternating-to-mean load ratios) shows small second stage creep and very small, if any, third stage creep prior to fracture. Thus, the static curves are the lowest of the group and have the greatest slope at intermediate and long life, whereas the dynamic curves are the highest and almost horizontal. From this figure it is seen that the relationship of alternating-to-mean load ratios to both elevation and slope of the curves is reasonably consistent.

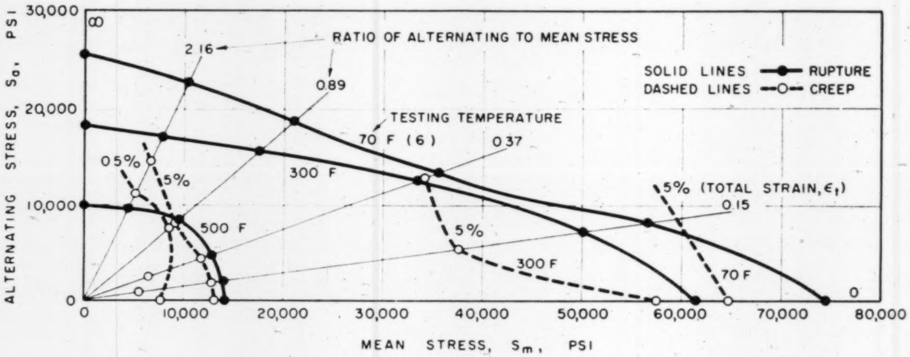

Fig. 11.—Dynamic Creep and Rupture Properties for 50-hr Life for Rolled Aluminum Alloy 24S-T4 at 70, 300, and 500 F.

By this type of analysis the 300-F creep curves are shown to be of the static type at A of 0 and 0.15, of the dynamic type at A of 2.0 and ∞, and not well defined at A of 0.37 and 0.89, but more dynamic than static. From Fig. 8 it is seen that at 500 F the creep curves are static at all ratios A up to and including 0.89 and dynamic at ratios A of 2.0 and ∞.

Figures 9 and 10, similar to the stress-range diagrams of Fig. 6, show the stress combinations which cause various total strain for definite times at stress. The stress-rupture curves ($A = 0$) from Figs. 2 and 3 are also replotted in these figures for completeness. The construction of Figs. 9 and 10 require the extrapolation of some of the creep curves beyond the rupture point. This represents, of course, an impossible physical situation but does permit development of certain creep-time-stress concepts discussed later which are useful for evaluating the rôle of creep in defining failure.

The general shape of the creep stress-range diagrams, for example see lower left set of Fig. 10, is similar to that predicted by theory (1). One would expect the curves to become asymptotic to the ordinate axis, since under reversed stress very little creep is to be expected.

Due to the small creep at 300 F the creep data for stress ratios $A = 0$, 0.15, and 0.37 only could be plotted. The stress combination curves for these ratios A show that when alternating stress is superimposed on mean stress the same general effect is observed for creep as for rupture. At 500 F, sufficient creep occurred to allow plotting all but the $A = \infty$ curve. Again, the shape of the creep curves, Fig. 10, is similar to the shape of the rupture curves up to ratio $A = 0.89$ and show that alternating stress lowers only slightly the allowable mean stress at low ratios A. For ratios above 0.89 the curves turn upward, and unlike the rupture curves become asymptotic to the ordinate axis.

In order to clarify the rôle of both creep and fatigue as factors in rupture, selected data from Figs. 9 and 10 and from a previous room-temperature investigation (6) have been analysed and Fig. 11 developed. This figure shows the stress combinations required for rupture and certain selected amounts of total strain for 50-hr life. The intersection of the creep and rupture curves indicates the stress combination at which a transition occurs; to the left of the intersection, fatigue governs as a cause of rupture, and to the right, creep may be the critical factor in design. Similar curves may be constructed for other lives and creep magnitudes.

At room temperature the 5 per cent total strain curves intersect the rupture curve at a low ratio, $A = 0.08$, and this indicates that for stress combinations up to 0.08 creep may govern a design, but above this ratio fatigue governs. At 300 F this ratio increases to about 0.37, whereas at 500 F it becomes about 1.0. This increase in ratio A with increasing temperature indicates the increasing influence of creep and the decreasing effect of fatigue as the dominant factor. As the temperature increases from room temperature to 500 F, creep and stress-rupture considerations become more important and fatigue less important.

SUMMARY AND CONCLUSIONS

A series of axial stress tests were undertaken on 24S-T4 rolled aluminum to determine the effect of various combinations of alternating and mean stress on the fatigue, stress-rupture, and creep properties at 300 and 500 F. The stress range from static tension to reversed axial stress was covered in six alternating-to-mean load ratios A, and stress combinations were varied to produce rupture in the range from 10^3 to 2×10^7 cycles (0.3 to 100 hr).

The basic fatigue data are presented in S-N curves and stress-range diagrams to show the effect of temperature on fatigue life. The extension data are presented on log-log and other types of plots to show the relation between stress, time, and per cent extension. The extension curves are analysed by graphical means and classified into two types: static and dynamic. The relative effect of creep and fatigue on rupture is investigated, and diagrams are shown which indicate how these factors are affected by temperature and alternating-to-mean load ratio.

The following conclusions are based on the fatigue, stress-rupture, and creep data presented in this paper.

1. At 300 F the fatigue behavior is similar to that at room temperature. First, the S-N curves display a reasonably well pronounced knee, and secondly, increasing ratio A lowers the entire curve for maximum stress plots.

2. At 500 F the fatigue behavior is significantly different. First, there is no knee to the S-N curves; in fact, the slope increases with increasing life. Also, for maximum stress plots, the vertical location is not in order of ratios; the static curve is midway in the family, the $A = 0.89$ curve is highest, and the $A = \infty$ curve is lowest. This vertical location is related to the prominence of creep as a cause of rupture at 500 F.

3. The stress-range diagrams plotted indicate shapes for the room temperature and 300 F data pronouncedly different than for the 500 F data. The low temperature curves are reasonably close to straight lines on a unitless plot, whereas the 500 F data are better represented by an arc of a circle.

4. The creep properties are a function of temperature, ratio A, and mean stress. The higher the temperature, the lower is the ratio A, and the greater the mean

stress the greater the creep. Maximum creep occurs at ratio A of 0 at 500 F, whereas no observable creep occurs at A of ∞ at 300 F.

5. The character of the creep curve is also influenced by alternating-to-mean load ratio and temperature. The characteristic three stage creep curve is termed the static type, and a creep curve having almost zero creep rate during second stage and very little third stage creep prior to rupture, the dynamic type. It is shown that at 300 F the curves at ratios A of 0 and 0.15 are static, A of 2.0 and ∞ are dynamic, and A of 0.37 and 0.89 not clearly defined but more dynamic than static. At 500 F the distinction between the two is better defined, the static creep occurring at A of 0, 0.15, 0.37, and 0.89, and dynamic creep at A of 2.0 and ∞.

6. In general, superimposing alternating stress on mean stress affects creep in a manner similar to that observed in fatigue. At 300 F superimposing alternating stress on mean stress significantly decreases the allowable mean stress for a given allowable creep. At 500 F this effect is considerably less pronounced.

7. The rôle of fatigue and creep as factors in failure is a function of temperature and alternating-to-mean load ratio. As the temperature increases, fatigue considerations become less important and creep factors predominate. The ratio A at which the dominating rôle changes from creep to fatigue depends on the test temperature. For example, for 50-hr life and 5 per cent total strain this critical ratio A is 0.08 at room temperature; at 300 F it becomes 0.37; and at 500 F it is about 1.0. For stress combinations giving ratios A less than these values, the dominant factor in design may be creep; whereas for stress combinations of higher ratios A the dominant factor is fatigue.

Acknowledgment:

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REFERENCES

(1) B. J. Lazan, "Dynamic Creep and Rupture Properties of Temperature-Resistant Materials Under Tensile Fatigue Stress," *Proceedings*, Am. Soc. Testing Mats., Vol. 49, p. 757 (1949).

(2) B. J. Lazan and E. Westberg, "Effect of Tensile and Compressive Fatigue Stress on Creep, Rupture, and Ductility Properties of Temperature-Resistant Materials," *Proceedings*, Am. Soc. Testing Mats., Vol. 52, p. 837 (1953).

(3) B. J. Lazan and F. W. DeMoney, "Investigation of Axial Loading Fatigue Properties of Heat Resistant Alloy N-155," WADC Technical Report 52-226, Part I, March, 1953.

(4) W. J. Trapp, "Elevated Temperature Fatigue Properties of SAE 4340 Steel," WADC Technical Report 52-325, Part I, December, 1952.

(5) M. J. Manjoine, "Effect of Pulsating Loads on the Creep Characteristics of Aluminum Alloy 14S-T," *Proceedings*, Am. Soc. Testing Mats., Vol. 49, p. 788 (1949).

(6) B. J. Lazan and A. A. Blatherwick, "Fatigue Properties of Aluminum Alloys at Various Direct Stress Ratios, Part I, Rolled Alloys, Part II, Extruded Alloys," WADC Technical Report 52-307, Part I and II, December, 1952.

(7) H. V. Kinsey, "An Evaluation of the Effective Gage-Length Equivalent of the Fillet and Shoulder of the Gage Length Portion of a Tension Test Bar Under Creep and Stress-Rupture Conditions," ASTM BULLETIN No. 171, January, 1951, p. 60 (TP22).

(8) A. Nadai and P. G. McVetty, "Hyperbolic Sine Chart for Estimating Working Stresses of Alloys at Elevated Temperatures," *Proceedings*, Am. Soc. Testing Mats., Vol. 43, p. 738 (1943).

DISCUSSION

MR. J. M. LESSELLS.[1]—The paper adds considerably to the knowledge on the effect of cyclic stress on the creep and rupture strength of metals. It is interesting to observe, as indicated by Fig. 10, that the maximum stress of a cycle composed of a static stress plus a cyclic stress is greater than the creep or rupture stress for the same temperature. In other words, the presence of a cyclic stress increases the creep and rupture strength. This has already been shown to be true for gas-turbine superalloys.[2]

MR. LOUIS F. COFFIN, JR.[3]—The authors have reported a very interesting study of the effect of static and cyclic stress on an aluminum alloy at elevated temperatures. In examining the paper, however, the writer has found no mention of what to him would be a significant variable in the problem under study, namely, the speed of cycling. This important variable would have a very definite effect on the results reported. For example, if the speed of cycling was one cycle per minute or one cycle per hour, rather than many hundred cycles per minute, the results illustrated in Fig. 11, particularly at 300 and 500 F, might be significantly altered.

CHAIRMAN T. J. DOLAN.[4]—In connection with Fig. 8 of the paper, the data for extensions for the different conditions (or ratios of dynamic stress to static stress) were broken down into three distinct bands or groups. I should like to ask the authors if in each of these three bands they observed differences in type of failure; in other words, were fractures primarily of a transcrystalline type in one band as compared with intercrystalline fractures resulting from a different ratio of alternating to mean stress? Was it possible to distinguish between the characteristics of failure in these various bands?

MR. CLARENCE R. SMITH.[5]—I noticed that the authors use stress amplitude rather than what we call the stress ratio. What in particular led to the use of stress amplitude rather than other forms? Is it easier to plot, or is it easier to work with?

MR. B. J. LAZAN (*author*).—The shape of the stress-range diagrams, such as shown in Fig. 10, at small values of alternating to mean stress has been observed to be of various forms. In the case of many gas-turbine superalloys at high temperatures, small alternating stress appears to exert a strengthening effect as discussed by Mr. Lessells. In some cases however, notably for notched specimens, relatively small alternating stress may seriously reduce the allowable mean stress for a given time to failure. Thus, generalizations in this stress range should carefully consider factors of significance in engineering service.

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[1] President, Lessells and Associates, Inc., Boston, Mass.

[2] D. A. Oliver and G. T. Harris, "The Development of a High Creep Strength Austenitic Steel for Gas Turbines," *Journal*, West of Scotland Iron and Steel Inst., Vol. 54, p. 97 (1946–1947).

[3] Research Associate, Technical Department, Knolls Atomic Power Laboratory, Schenectady, N. Y. (operated for the U. S. Atomic Energy Commission by the General Electric Co.).

[4] Head of Department of Theoretical and Applied Mechanics, University of Illinois, Urbana, Ill.

[5] Research Test Engineer, Convair, San Diego Division, San Diego, Calif.

The speed of cyclic stressing was 3600 cpm, as described in reference (1) which describes the testing equipment used. The authors agree with Mr. Coffin that testing frequency may be a very significant variable in testing at elevated temperatures. Since factors such as creep, corrosion, and some types of metallurgical changes during a test are time sensitive, whereas other factors like fatigue and perhaps other types of metallurgical changes are cycle sensitive, the number of cycles per unit time may affect the relative importance of the individual factors and their method of combining to produce ultimate failure. A study of the frequency variable is, however, beyond the scope of this work. Recent, and as yet unpublished work at Cornell Aeronautical Laboratory should help clarify this variable. Progress reports from Cornell indicate that in the frequency range investigated, 0 (static test) to 3600 cpm, and at small ratios of alternating to mean stress, two different temperature-resistant materials show generally different behavior. Alloy N-155 showed relatively little change with frequency, whereas Inconel X showed a significant change in strength which could be associated with increasing frequency. Very recent work at Cornell shows that the strength of type 321 stainless alloy at 1500 F decreases greatly with decreasing frequency from 3600 to 11.5 cpm for alternating stress of 25 per cent and 67 per cent. Perhaps there is someone from Cornell in the audience who could further clarify this point.

Mr. Dolan inquires about the relationship of types of fractures observed to the various types of creep curves shown in Fig. 8 for the different ratios of alternating to mean stress. Relatively little work was done in this program on metallographically studying fractured specimens to determine the nature of the fracture, that is, whether transcrystalline or intercrystalline. However, the little work done in this and similar programs indicates that at the higher temperatures the static loading ($A = 0$) generally produces a failure which is generally intercrystalline, whereas under reversed stress ($A = \infty$) the failure tends to be generally transcrystalline or mixed. At intermediate values of ratio A, mixed transcrystalline and intercrystalline failures are generally observed. In general there appears to be no abrupt change with changing stress ratio.

In answer to Mr. Smith's question, the primary reason for using ratio of alternating to mean stress (ratio A) as a parameter is one of convenience in setting up test programs, handling data, and cross-plotting. Also in fatigue notch sensitivity work the handling of data procured at constant ratio A (as contrasted with constant mean stress or constant alternating stress) appear to be simpler since the fatigue strength reduction factor K_f is the same if either a mean stress or alternating stress basis of comparison is used. The ease of illustrating and interpreting ratio A in the stress range diagrams was also a factor in this choice of parameter.

The authors wish to thank the discussors for their aid in clarifying several of the points.

MR. E. J. WARD.[6]—I am not from Cornell but I am connected with that work. I think Mr. Lazan had the results of the work at Cornell essentially correct. The work so far has covered the three frequencies of the static 0, 150, and 3600 cpm. The two materials are N-155 and Inconel X, and the results do show different effects. The results show in one case the lowering of the strength, and I am not quite sure but I believe that it is the Inconel X where the increased frequency shows a lower strength.

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[6] Materials Laboratory, Wright Air Development Center, Dayton, Ohio.

I would like to point out that in the consideration of the effect of frequency, we have two things to consider, the number of cycles which are applied during a given time and the amount of creep which can take place. If the cycles of stress are applied at a slower rate, then there is a greater effect of creep, as there is a longer time. Therefore the failure may tend to be more of a creep failure than if the same number of cycles over a shorter period of time had been applied. I just wanted to bring out that the different frequencies are affecting the type of failure, whether it is more of a creep failure or more of a fatigue failure.

CHAIRMAN DOLAN.—This is a very important point; we are certainly fitting together "time-dependent" phenomena associated with creep and "cycle-dependent" phenomena due to fatigue. Furthermore, materials are being pushed up to the high temperatures at which they are metallurgically unstable; further precipitation or aging effects are occurring with *time*. Due to this complex conglomeration of these various factors, it is difficult to predict how the cyclic frequency may affect the results as compared with that for another material which may have different inherent instabilities from the metallurigical viewpoint.

THE INFLUENCE OF TEST TEMPERATURE AND GRAIN SIZE ON THE FATIGUE NOTCH SENSITIVITY OF REFRACTALOY 26*

By P. R. Toolin[1]

Synopsis

The influence on notch sensitivity of test temperature, 80 to 1600 F, and grain size, varied by solution treatment to ASTM No. 3.5 (coarse) and 7.5 (fine),[2] has been studied for the wrought, precipitation-hardened alloy Refractaloy 26.* Throughout the above temperature range, a decrease in grain size caused an increase in fatigue notch sensitivity. While the finer grained material had superior unnotched fatigue strength up to 1460 F, the presence of a notch decreased the relative superiority of the fine-grained material and lowered the temperature at which the coarse-grained material became superior. The notch sensitivities of specimens of both grain sizes reached maxima at about 1150 F.

Rather abrupt changes in section frequently are present in members which are subject to fatigue stressing at high temperatures. These changes or "notches" cause stress concentrations and reduce the fatigue strength of such members at elevated temperatures just as they do at room temperature. In order that better materials may be developed and that the best use may be made of the present ones, it is essential that information should be available on the factors which influence the amount of strength reduction caused by a notch. This paper is a study of the influence of temperature and grain size, as varied by solution treatment, on the notch sensitivity of Refractaloy 26.† It is an extension of a previous investigation (**1**)[3] of the factors which influence the fatigue strengths of unnotched specimens of this alloy at elevated temperature. Refractaloy 26 is one of several wrought precipitation-hardened alloys used for members operating at high temperatures.

Previous Work

The greater notch sensitivity of fine-grained steels has been pointed out by Peterson (**2, 3**), who suggested that the notch sensitivity may be a function of the stress gradient and grain size. Neuber (**4**) has also suggested that his theoretical stress concentration factors must be modified to accommodate crystalline engineering materials.

Karry and Dolan (**5**) made an excellent study of the relationship between grain size and notch sensitivity at room temperature for 70-30 brass. They showed that the notch sensitivity of brass increased as the grain diameter decreased.

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13–18, 1954.

† Registered trademark.

[1] Mechanics Department, Westinghouse Research Laboratories, East Pittsburgh, Pa.

[2] Tentative Methods for Estimating the Average Grain Size of Non-Ferrous Metals, Other than Copper, and Their Alloys (E 91 – 51 T), 1952 Book of ASTM Standards, Part 2, p. 1176.

[3] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 796.

TABLE I.—SUMMARY OF HEAT TREATMENTS, GRAIN SIZE, AND HARDNESS.

Code	Heat Treatment				Grain Size		Average Diamond Pyramid Hardness
	Solution Treatment		Aging Treatment, hr				
	Temperature, deg Fahr	Time, min	At 1500 F	At 1350 F	ASTM No.	Diam, mm	
1800C............	1800	20		44	7.5	0.027	345
1800AB............	1800	20	20	20	7.5	0.027	310
2100AB............	2100	60	20	20	3.5	0.107	300

TABLE II.—SUMMARY OF FATIGUE STRENGTH RESULTS.

Test Temperature, deg Fahr	Heat Treatment Code[a]	ASTM Grain Size No.	At 10^6 Cycles				At 10^8 Cycles			
			Fatigue Strength, psi		K_f[c]	q[d]	Fatigue Strength, psi		K_f[c]	q[d]
			Smooth	Notched[b]			Smooth	Notched[b]		
Room.....	1800C	7.5	85 000	57 000	1.49	0.39	74 000	48 000	1.54	0.43
Room.....	1800AB	7.5	85 000	51 000	1.68	0.53	74 000	45 000	1.65	0.51
Room.....	2100AB	3.5	63 000	52 000	1.21	0.17	45 000	42 000	1.07	0.06
800.......	1800C	7.5					75 000[e]			
1050......	1800C	7.5	85 000	49 000	1.74	0.58	84 000	48 000	1.75	0.58
1200......	1800C	7.5	90 000	51 000	1.77	0.60	84 000	47 000	1.79	0.62
1200......	1800AB	7.5	85 000	44 000	1.93	0.73	73 000	41 000	1.78	0.61
1200......	2100AB	3.5	59 000	44 000	1.34	0.27	52 000	42 000	1.24	0.19
1500......	1800C	7.5					34 000	25 000	1.36	0.28
1500......	2100AB	3.5	44 000	35 000	1.26	0.20	37 000	34 000	1.09	0.07
1600......	2100AB	3.5	31 000				23 000			

[a] The corresponding heat treatments are given in Table I.

[b] Semicircular notch: 0.015-in. radius, 0.015-in. depth, $K_t = 2.27$.

[c] Fatigue strength reduction factor, K_f = unnotched fatigue strength divided by notched fatigue strength.

[d] Fatigue notch sensitivity factor, $q = \frac{K_f - 1}{K_t - 1}$.

[e] This fatigue strength is based on only one test.

Breen and Lane (6) investigated the effect of grain size on the stress rupture and range-of-stress fatigue strengths of unnotched 70-30 brass over the temperature range from 80 to 1000 F. For precision-cast alloy X-40, it was found (7) that specimens with grains of about 1.25 mm average diameter had greater fatigue strength at 80, 1200, and 1600 F than did those with very large grains. However, the greater notch sensitivity of the smaller grained X-40 specimens resulted in the notched fatigue strength of the small- and the large-grained specimens being about the same.

Investigations of the effect of temperature on fatigue notch sensitivity have also been made by Jones and Wilkes (8), Demer and Lazan (9), and Trapp and Schwartz (10).

The influences of temperature, composition, heat treatment, hardness, and grain size upon the unnotched fatigue strength of Refractaloy 26 have been previously reported (1). It was determined that composition changes in the amount normally found in commercial heats do not appreciably affect the unnotched fatigue strength. A lack of correlation between hardness and unnotched fatigue strength was also found. Temperature, heat treatment, and grain size were shown to have definite influences upon the unnotched fatigue strength.

MATERIAL

This investigation has been made on the wrought austenitic precipitation-hardened alloy Refractaloy 26. Much of the data on unnotched specimens has been taken from a previous paper (1). The analyses of the four heats used in that investigation are given therein. An analysis made on the present lot of $\frac{5}{8}$-in. diameter bar stock showed: 35.4 per cent nickel, 21.4 per cent cobalt, 18.5 per cent chromium, 2.99 per cent molybdenum, 2.63 per cent titanium, 0.14 per cent aluminum, 1.13 per cent silicon, 0.86 per cent manganese, and the balance iron.

The heat treatments used in the present investigation and their code designations, the mean grain sizes, and the hardnesses of the heat-treated material are given in Table I. These heat treatments do not yield material that is completely stable at the higher test temperatures. All three heat treatments resulted in materials whose hardness increased during the tests at 1050 and 1200 F and decreased during the 1500 and 1600 F tests.

TEST PROCEDURE

The fatigue tests were made in Westinghouse Type MD high-temperature fatigue machines. In these repeated-bending machines, the specimen is a nonrotating cantilever which, for these tests, was subjected to completely reversed bending at a frequency of 7200 cpm. The room-temperature dimensions were used to calculate the nominal stress by normal elastic beam theory. The test temperatures were determined by use of a thermocouple spot welded to the specimen on the neutral axis at the critical section. All specimens were left at the test temperature overnight, 16 to 19 hr, before the tests were started.

The criterion of failure was that a fatigue crack should grow to such size, normally less than 0.1 in. penetration, that it would cause the automatic-shutdown circuit of the fatigue machine to operate.

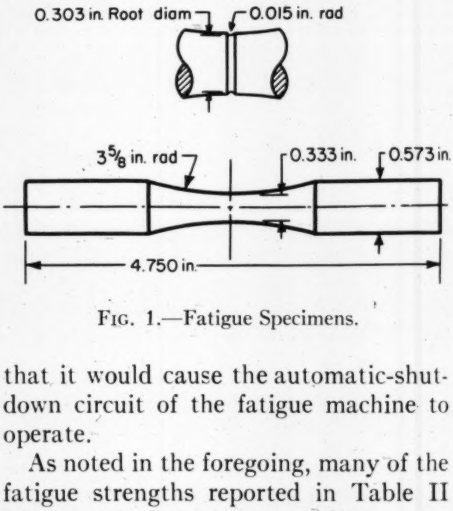

FIG. 1.—Fatigue Specimens.

As noted in the foregoing, many of the fatigue strengths reported in Table II for unnotched specimens are from a previous paper (1). To establish that the unnotched fatigue strengths of the material used in the present investigation were not significantly different from the above strengths, check tests were made at all temperatures. Where the previous paper had no information, *S-N* diagrams were determined using the new lot of Refractaloy 26.

The unnotched fatigue specimen is shown in Fig. 1. These specimens were rough machined to 0.025 in. oversize and then machined with diminishing cuts. The final 0.002 in. was removed by polishing successively with 180, 400, and 600 mesh abrasive. The final polishing was done in the longitudinal direction and gave a finish of less than 10 microinches, rms. The notched specimen was identical to the unnotched except that a 0.015-in. radius semicircular groove 0.015 in. deep was located at the minimum section. This notch was formed by a contoured A-80-V2-BT wheel, 6-in. diameter, rotating at 5200 rpm with an infeed of 0.000006 in. per revolution of the specimen. The specimen was rotated at 1100 rpm with opposite rotation to the grinding wheel. A coolant was used. The notch was left as ground.

The theoretical factors (11) for the notched specimen of Fig. 1 are $K_t = 2.27$ and $K_t' = 2.07$.

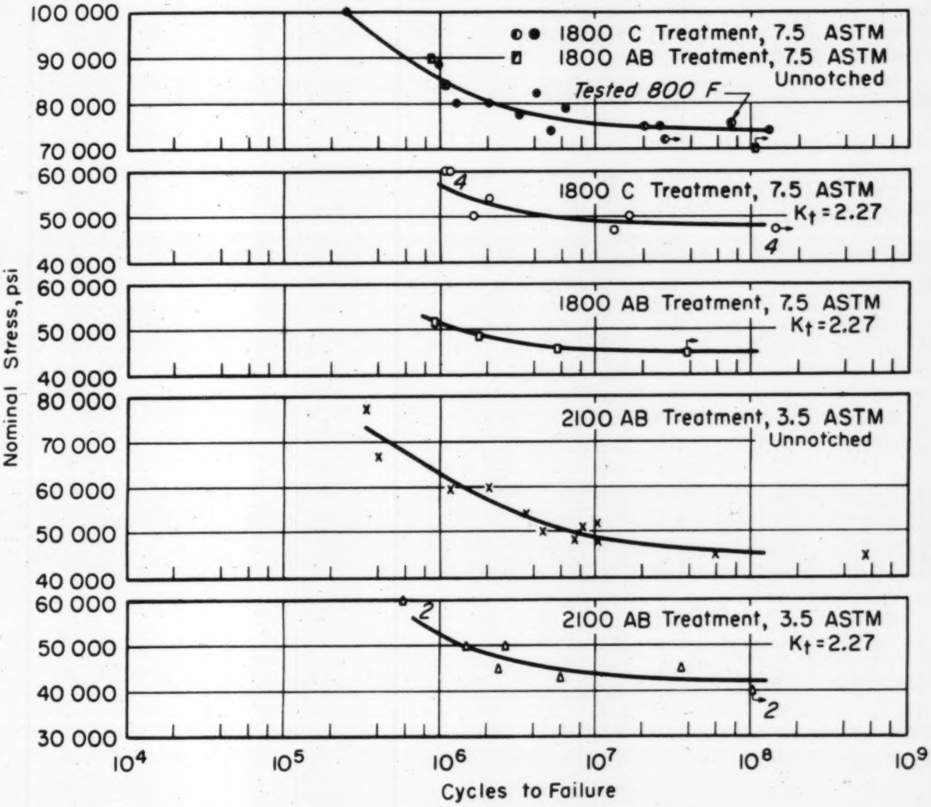

FIG. 2.—*S-N* Diagrams for Refractaloy 26 at Room Temperature.

RESULTS AND DISCUSSION

In considering the fatigue test results, it should be remembered that fatigue strengths of notched specimens, fatigue strength reduction factors, and notch sensitivity factors are all influenced by the geometry of the notched specimen. Thus, for example, the curves for notch sensitivity *versus* temperature in Fig. 6 are each but one of a family of curves.

It should also be noted that while the notches were formed by gentle grinding, the unnotched specimens were machined and polished. These latter operations may work harden and leave compressive

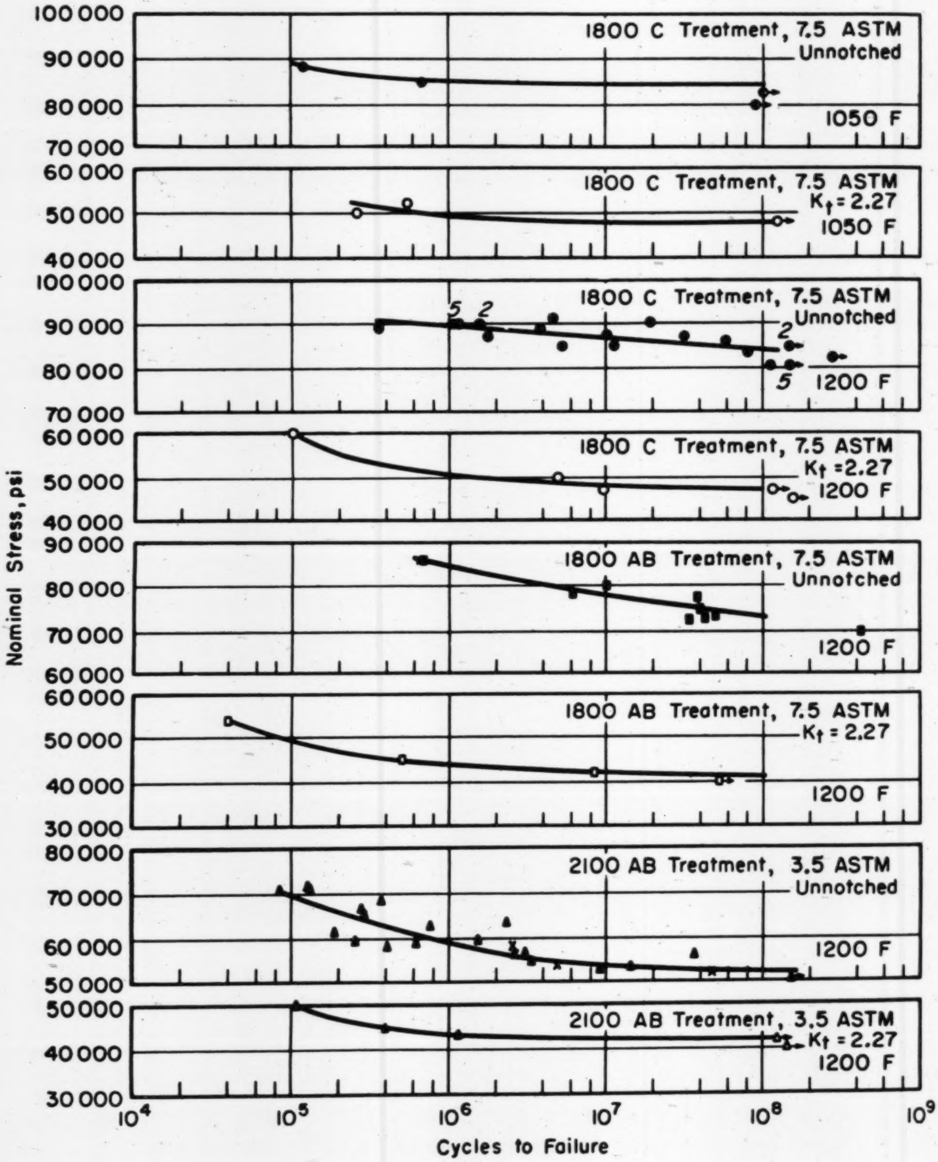

FIG. 3.—*S-N* Diagrams for Refractaloy 26 at 1050 and 1200 F.

stresses in the specimen surface. This may result in the room-temperature fatigue strengths found for the fine-grained material being somewhat greater than what might be called the true fatigue strength. Other work on Refractaloy 26 has shown that for fine-grained specimens gently ground to a 30 to 40 microinch rms finish, the fatigue strength at room temperature may be as much as 25 per cent less than that of machined and polished specimens. At 1200 F this difference is less than 10 per cent. For material corresponding to the 2100AB material herein, there appears to be little difference at room temperature between ground and machined-and-polished specimens. Ferguson (12) has shown that the fatigue strength of the austenitic high-temperature alloy N-155 is decidedly sensitive to the finishing procedure used. For precision cast X-40 (7), specimens having machined notches were found to have greater 1200 F fatigue strengths than those with ground notches.

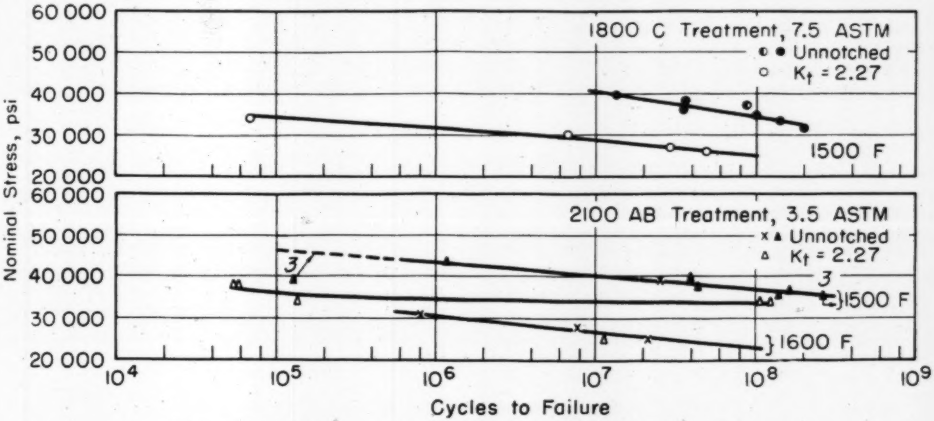

FIG. 4.—*S-N* Diagrams for Refractaloy 26 at 1500 and 1600 F.

A final point is that the two grain sizes were obtained by using two different solution treatments, Table I. Consequently, it is possible that there may be metallurgical dissimilarities other than grain size.

S-N Curves:

With the preceding cautions in mind, consideration can be given to the fatigue test results which are presented in the *S-N* diagrams of Figs. 2, 3, and 4. In these, the test points from the previous paper (1) on Refractaloy 26 have been assigned solid symbols so that the lack of significant difference between the unnotched fatigue strengths of the two series may be observed. Also, the tests which "ran out" and were rerun at a higher stress have been numbered at both stresses.

At room temperature, the slope of the *S-N* curves for both the unnotched and the notched specimens becomes relatively small at 10^7 cycles. However, true fatigue limits are not indicated. The fatigue strength reported for 800 F is based upon the one test shown in Fig. 2. At 1050 F, because of the strain aging which this material exhibits in the tension test, it is thought that a fatigue limit may exist. At 1200 and 1500 F, the *S-N* curves for the unnotched specimens have appreciable slopes throughout the range investigated. Beyond 5 × 10^6 cycles the curves for the notched specimens at these temperatures have less slope than do those for the unnotched specimens. This results in a decreasing notch sensitivity with increasing cycles. This phenomenon was also observed (7) for precision-cast X-40 at 1200 and 1600 F.

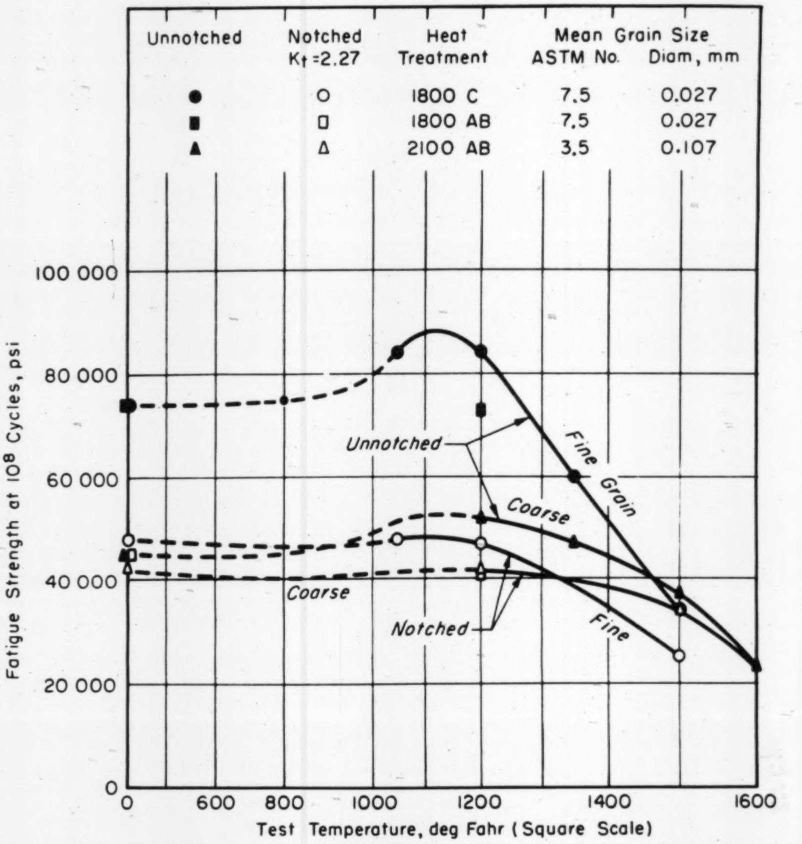

FIG. 5.—Influence of Temperature on Fatigue Strength at 10^8 Cycles of Refractaloy 26.

Fatigue Fractures:

Representative fatigue specimens from each test temperature were sectioned and examined. At all the test temperatures, the fatigue fractures, for both grain sizes, appear to progress in a transcrystalline manner. However, the possibility does exist that at 1500 and 1600 F the fractures may start at points of intergranular oxidation.

Many of the room-temperature tests were observed with the aid of microscopes in order that the fatigue fractures could be noted early in their life. The earliest, percentagewise, that a fracture was observed was at 3 per cent of a total life of 8,600,000 cycles for an unnotched, coarse-grained, 2100AB specimen. In general, for a given life, the fractures appear to progress faster in the fine-grained material than in the coarse-grained material. Of course, the room-temperature fatigue strength of the fine-grained material is considerably higher than that of the coarse-grained.

The notched specimens of 1800C and 2100AB materials which ran out at the higher stresses at 1200 F were sectioned. Small cracks, the deepest being 0.005 in., were found in the notch roots of both specimens. The starting time and the rate of progression of these cracks are unknown. No cracks were revealed by the sectioning of the notched 1800C specimen which did not fail at 1050 F.

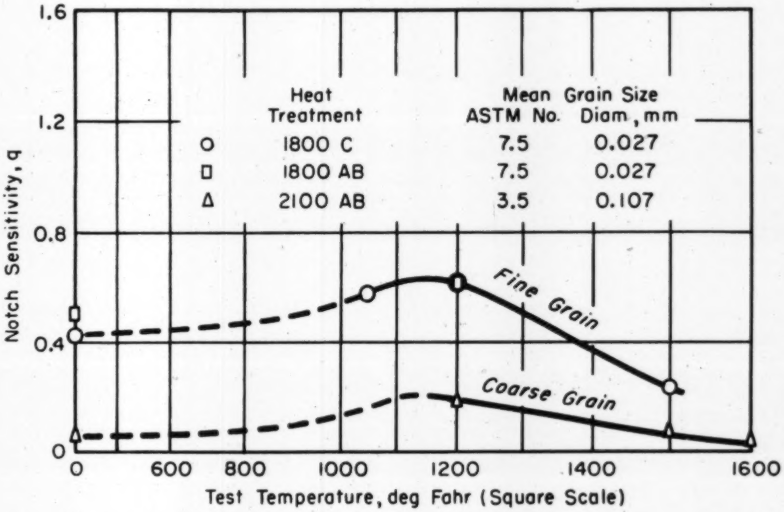

FIG. 6.—Influence of Temperature on Notch Sensitivity, q, at 10^8 Cycles of Refractaloy 26, 0.015-in. Semicircular Notch, $K_t = 2.27$.

Influence of Temperature and Grain Size on Fatigue Strength:

The fatigue strengths have been tabulated in Table II and plotted against test temperature in Fig. 5. Figure 5 shows that the 10^8 cycle fatigue strength of both the 1800C and the 2100AB material is greater at 1200 F than at room temperature. (This is presumably due to aging and strain aging.) However, the *S-N* curves show that at 10^5 cycles these materials are weaker at 1200 F than at room temperature. While the 10^8 cycle fatigue strength at 1200 F of the 1800AB material is less than that at room temperature, it is possible that the 1100 F strength would be slightly greater. It appears less likely that this would be true for the notched 1800AB specimens.

For the unnotched specimens the fine-grained material has a very considerable advantage at temperature up to 1200 F. Above 1200 F this superiority decreases until at about 1460 F the unnotched 1800C and 2100AB fatigue strengths are equal. (The fatigue strengths of the 1800C and the 1800AB materials presumably will approach each other as the temperature is increased above 1200 F.) However, for the notched specimens the fine-grained material has less superiority at the lower temperatures. Also the temperatures at which the fine- and coarse-grained notched specimens have equal strengths are lower than the above 1460 F. The coarse-grained notched specimens are superior to the 1800AB specimens above 1200 F and superior to the 1800C specimens above about 1330 F. These cross-over points are, of course, also influenced by the specimen geometry.

It is noteworthy that, while the unnotched fatigue strengths of the 1800C and the 2100AB materials increase 14 and 16 per cent respectively in going from room temperature to 1200 F, the corresponding notched fatigue strengths show a decrease of 2 per cent and zero. Similarly the unnotched fatigue strength of the 1800AB material decreased 1 per cent, while the notched strength dropped 9 per cent. Thus for applications with stress concentrations, the peak in the unnotched fatigue strength *versus* temperature curve gives an unduly optimistic picture.

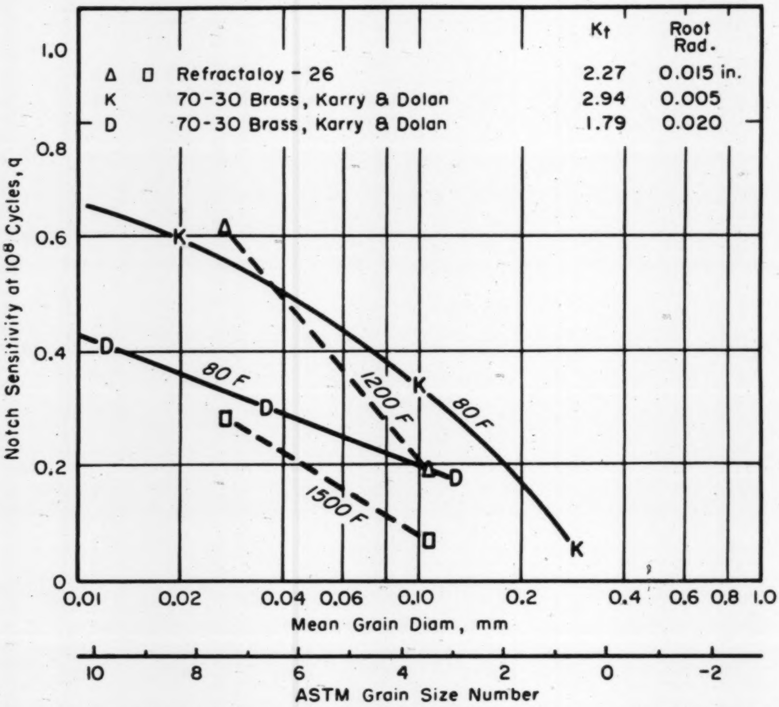

FIG. 7.—Influence of Grain Size on the Fatigue Notch Sensitivity, q, of Refractaloy 26 and 70-30 Brass, the Latter Taken from Karry and Dolan (5).

Influence of Temperature on Notch Factor and Sensitivity:

The terms used herein are in accordance with the ASTM Committee E-9's Manual on Fatigue Testing (13.) The fatigue strength reduction factor, K_f, is defined by:

$$K_f = \frac{\text{unnotched fatigue strength}}{\text{notched fatigue strength}}$$

Fatigue notch sensitivity, q, is defined by:

$$q = \frac{K_f - 1}{K_t - 1}$$

where K_t is the theoretical stress concentration factor.

Since K_f and q are related by the above expression, a plot of K_f *versus* temperature would be similar to that for q *versus* temperature in Fig. 6, and the two factors may be discussed simultaneously. These factors, like the fatigue strengths, reach maxima in the 1100 to 1200 F range. These maxima are presumably due to the aging characteristics of this alloy.

For SAE 4340, Trapp and Schwartz (10) found that the q at 600 F was greater than at room temperature or 800 F. However, their highest fatigue strengths were at room temperature.

Over the temperature range investigated, 80 to 1500 F, both K_f and q for the fine-grained material are considerably greater than those for the coarse-grained material. This greater notch sensitivity results in the fatigue strengths at 1200 F of the notched 1800AB and 2100AB specimens being about the same, while the corresponding unnotched fatigue strength of the fine-grained 1800AB material is 40 per cent greater than that of the 2100AB material.

The tests at 1600 F indicate that the notch sensitivity of the coarse-grained 2100AB material is approaching zero at that temperature.

Influence of Grain Size on Notch Sensitivity:

The notch sensitivity factors, q, for Refractaloy 26 at 1200 and 1500 F have been plotted against the grain size in Fig. 7. At both temperatures q increases as the grain size decreases, but the increase is considerably less at 1500 than at 1200 F. The room temperature values are not shown because they may have been influenced by the specimen preparation. However, even if reasonable allowance is made for this, q will also increase with decreasing grain size at room temperature. The results of Karry and Dolan (5) for 70-30 brass, for grain sizes greater than 0.01 mm mean diameter, are also shown in Fig. 7. At 1200 F, the notch sensitivity of Refractaloy 26 is more sensitive to change in grain size than brass is at room temperature. In view of the fact that brass is a single phase alloy, while Refractaloy 26 is a complex precipitation-hardened alloy, it is perhaps surprising that the curves for the two materials fall as closely as they do. Also, the grain size of Refractaloy 26 has a rather broad distribution about the mean. Should the fatigue strength be more dependent upon the size of the larger grains than upon the mean size, the slope of the lines for Refractaloy 26 might be altered.

For precision-cast X-40 (7) at 1200 F, fatigue notch sensitivities of 0.46 and 0.28 were obtained for specimens having cast grains of about 1.25 mm and 1 cm mean diameter, respectively. The specimen and notch were identical to the one used for Refractaloy 26. This q of 0.28 for the 1.25-mm grain diameter cast X-40 is greater than the q of 0.19 found for the 0.107-mm grain diameter Refractaloy 26.

Demer and Lazan's data (9) yield a notch sensitivity of 0.53 for N-155 tested at 1350 F with a notch of 0.010 in root radius and a K_t of 2.6. This notch sensitivity is greater than the 0.45 which Fig. 6 indicates for Refractaloy 26 of mean grain size ASTM No. 7.5. On the basis of the fact that the N-155 has larger grains, about ASTM No. 5, and was tested[4] with a notch of smaller root radius, one would predict that the notch sensitivity found for the N-155 would be lower than that for the Refractaloy 26 The incorrectness of such a prediction and the above comparison of Refractaloy 26 and X-40 gives further substantiation to the generally accepted view that q depends on geometry, composition, and the specific condition of the material.

CONCLUSIONS

The following conclusions are based upon repeated-bending fatigue tests made with completely reversed loading at 7200 cpm on the wrought, precipitation-hardened alloy Refractaloy 26. The two mean grain sizes of ASTM Nos. 3.5 and 7.5 which were investigated were obtained by two different solution treatments. The unnotched specimens were machined and polished; and the notches, 0.015-in. semicircular, $K_t = 2.27$, were formed by gentle grinding. The specimens were stabilized overnight at the test temperatures.

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[4] The testing frequency used for the N-155 was substantially lower than that for the Refractaloy 26.

Over the temperature range of 80 to 1500 F, the fatigue notch sensitivity, q, of Refractaloy 26 increases as the mean grain diameter is decreased from 0.11 to 0.027 mm (the range investigated).

The fatigue strengths, unnotched and notched, of the single-aged, 1800 F solution-treated material and of the double-aged, 2100 F solution-treated material reach maxima between 1100 and 1200 F. The double-aged, 1800 F solution-treated material appears to be less susceptible to strain aging, and it is probable that only the unnotched fatigue strength has a maximum.

The maximum notch sensitivity occurs at the above temperature of maximum fatigue strength for both grain sizes investigated.

The presence of a stress concentration lowers the temperature at which the fine- and the coarse-grained materials have equal fatigue strengths. Below this temperature, stress concentrations also reduce the relative superiority of the fine-grained material.

Acknowledgment:

The encouragement and assistance of R. E. Peterson are gratefully acknowledged. Note should also be made that the composition and heat treatment of Refractaloy 26 were developed by H. Scott, R. B. Gordon, and F. C. Hull. The assistance of the other members of the Westinghouse Research Laboratories, particularly that of W. F. Gabrys, is also acknowledged.

REFERENCES

(1) P. R. Toolin and F. C. Hull, "Fatigue Strength of Refractaloy 26 as Affected by Temperature, Hardness, and Grain Size," *Proceedings*, Am. Soc. Testing Mats., Vol. 52, p. 791 (1952).

(2) R. E. Peterson, "Methods of Correlating Data from Fatigue Tests of Stress Concentration Specimens," Stephen Timoshenko 60th Anniversary Volume, The Macmillan Co. (1938).

(3) R. E. Peterson, "Relation Between Life Testing and Conventional Tests of Materials," ASTM BULLETIN, No. 133, March, 1945, p. 9.

(4) H. Neuber, "Theory of Notch Stresses," Translated by F. A. Raven, J. W. Edwards Brothers, Inc., Ann Arbor, Mich. (1946).

(5) R. W. Karry and T. J. Dolan, "Influence of Grain Size on Fatigue Notch-Sensitivity," *Proceedings*, Am. Soc. Testing Mats., Vol. 53, p. 789 (1953).

(6) J. E. Breen and J. R. Lane, "Effect of Grain Size on High Temperature Fatigue Properties," *Transactions*, Am. Soc. Metals, Vol. 46, p. 1021 (1954).

(7) P. R. Toolin, "The Effect of Grain Size Upon the Fatigue Properties at 80, 1200, and 1600 F of 'Precision Cast' Alloy X-40," Symposium on Strength and Ductility of Metals at Elevated Temperatures, Am. Soc. Testing Mats., p. 142 (1952). (Issued as separate publication *ASTM STP No. 128*.)

(8) W. E. Jones and G. B. Wilkes, "Effect of Various Treatments on the Fatigue Strength of Notched S-816 and Timken 16-25-6 Alloys at Elevated Temperatures," *Proceedings*, Am. Soc. Testing Mats., Vol. 50, p. 744 (1950).

(9) L. J. Demer and B. J. Lazan, "Damping, Elasticity, and Fatigue Properties of Unnotched and Notched N-155 Alloy at Room and Elevated Temperature," *Proceedings*, Am. Soc. Testing Mats., Vol. 53, p. 839 (1953).

(10) W. J. Trapp and R. T. Schwartz, "Elevated Temperature Fatigue Properties of SAE

4340 Steel," *Proceedings*, Am. Soc. Testing Mats., Vol. 53, p. 825 (1953).

(11) R. E. Peterson, "Stress Concentration Design Factors," John Wiley and Sons, Inc., New York, N. Y. (1953).

(12) R. R. Ferguson, "Effect of Surface Finish on Fatigue Properties at Elevated Temperatures," *Research Memo RM E51D17*, Nat. Advisory Comm. Aeronautics (1951).

(13) ASTM Committee E-9, Manual on Fatigue Testing, Am. Soc. Testing Mats. (1949). (Issued as separate publication *ASTM STP No. 91.*)

DISCUSSION

MR. E. J. WARD.[1]—Mr. Dorn at California has been working on a project for us in which he has been investigating the effect of grain size on the unnotched fatigue properties of two heat-resistant alloys. He found that, when he arrived at the grain size by different heat-treating methods, he did not get the same fatigue strength. This substantiates Mr. Toolin's statement that it is not only the effect of grain size but other effects not yet understood which affect fatigue strength.

MR. P. R. TOOLIN (*author's closure*).—Mr. Ward's pertinent discussion is very much appreciated. Dorn's results, to which Mr. Ward refers, are interesting and not surprising. When the grain size is changed by variation of the time or temperature of the solution treatment, there may be concomitant changes in the structure such as variation in both the degree of solution and the homogeneity of the hardening constituents. Undoubtedly the strength of the material is also influenced by these changes in structure. It is for this reason that it has been emphasized that our two grain sizes were obtained by two different solution treatments.

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EFFECT OF RANGE OF STRESS AND PRESTRAIN ON THE FATIGUE PROPERTIES OF TITANIUM*

By J. P. Romualdi[1] and E. D'Appolonia[1]

Synopsis

The effects of range of stress and prestrain on the fatigue properties of titanium alloy, cold drawn and annealed (equal to RC-55), were studied on rotating-beam machines which permit a full range of loading from pure bending to pure tension in any combination. Complete reversal fatigue tests were also conducted on Ti-75A titanium alloy.

The effects of rate of strain and internal heating were determined by conducting tests at different speeds and under isothermal conditions. Mechanical tests were conducted on the titanium alloys and correlations between static properties and fatigue properties are given. The data were also analyzed to show the effect of hardness and different chemical composition on the fatigue properties.

Titanium, with a strength-weight ratio greater than that of aluminum or steel, shows promise of being a strategic structural metal, particularly in the aircraft industry.

Fatigue data for titanium are meager. A comprehensive bibliography on titanium, published by Battelle Memorial Inst. (1)[2] in 1952, makes no listing of references on fatigue of titanium. The few reports and papers that give fatigue data are not primarily concerned with the dynamic properties of the metal. Research is needed to determine such properties of this new material when it is used in structures subjected to pulsating loads. This paper presents results of such tests completed at Carnegie Institute of Technology (2).

Range-of-stress tests were conducted on rotating-beam fatigue machines designed to permit a full range of loading from pure bending (complete stress reversal) to pure tension. Tests were conducted at complete reversal on specimens prestrained in tension. To reduce the scatter in test results, the material was classified according to hardness and heat number and then tested. Specimens of the same hardness were selected from different heat numbers to determine the effect of composition and processing of titanium on its fatigue characteristics. Tests were also conducted at different speeds and with the specimens in a circulating water bath to determine the effects of testing speed and internal heating. This paper summarizes and correlates static and fatigue test results for two titanium alloys.

Material Used

One of the two alloys tested in this investigation consisted of $\frac{7}{8}$-in. diameter

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13–18, 1954.

[1] Research Assistant and Associate Professor of Civil Engineering, respectively, Carnegie Institute of Technology, Pittsburgh, Pa.

[2] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 815.

TABLE I.—CARBON AND NITROGEN COMPOSITION OF RC-55 TITANIUM ALLOY.

Heat	Carbon, per cent	Nitrogen, per cent
RIA-125D	0.140	0.035
RIA-125C	0.156	0.040
RIA-125B	0.180	0.050
RIA-120	0.146	0.045
RIA-122A	0.188	0.045
RIA-126B	0.185	0.059
RIA-110	0.160	0.050

TABLE II.—MECHANICAL PROPERTIES OF TITANIUM, TYPE Ti-75A.
Heat L-339, Annealed and Ground

Property	Specimen	
	No. 1	No. 24
TENSION TEST		
Proportional limit (Tension) psi	24 000	22 000
Nominal ultimate stress, psi	84 500	78 000
True ultimate stress at fracture, psi	129 000	132 000
Modulus of elasticity, psi × 10^{-6}	17.3	17.3
Per cent elongation (2-in. gage length)	33.5	34.5
Per cent reduction in area	51.6	53.5
Yield strength (0.2 per cent offset), psi	55 000	53 500
Hardness, Rockwell C	19.1	18.5
Fatigue strength at 10^7 cycles, psi	52 000	52 000
TORSION TEST		
Shearing strength at proportional limit, psi	24 000	24 000
Nominal ultimate shearing stress, psi	83 000	83 000
Angle of twist at fracture, rad per in.	4.95	4.95
Modulus of rigidity, psi × 10^{-6}	5.40	5.40
COMPRESSION TEST		
Proportional limit, psi	42 500	42 500
Yield strength (0.2 per cent offset), psi	65 000	65 000
Modulus of elasticity, psi × 10^{-6}	17.0	17.0

rod, type Ti-75A, annealed and ground, manufactured by the Titanium Metals Corp. of America. This alloy, with a titanium content exceeding 99.5 per cent, is designated as "commercially pure." The material as reported in the Handbook of Titanium Metal (3) has a nominal composition of: 0.10 per cent iron, 0.02 per cent nitrogen, less than 0.08 per cent tungsten, less than 0.04 per cent carbon, a trace of oxygen, and the remainder titanium.

The other alloy consisted of $\frac{5}{8}$-in. diameter rod (carbon electrode process) cold drawn and annealed (equal to RC-55), manufactured by Republic Steel Corp. The chemical analysis available listed the percentage of carbon and nitrogen for the RC-55 titanium alloy (see Table I).

The RC-55 alloy contained a few hundredths of one per cent of oxygen and iron, other elements a trace, and titanium 99 per cent plus.

STATIC TESTS

The entire stock of RC-55 alloy was cut up into 26-in. sections and hardness tests were then made at 3-in. intervals along each bar.

Mechanical tests were performed on both titanium alloys, some results of which are summarized in Tables II and III together with results of fatigue tests for purposes of correlation.

Figures 1 and 2 show typical stress-strain curves for the RC-55 and Ti-75A titanium alloys. The curves are divided into two parts. The first portion has an expanded scale for the elastic and initial plastic range up to 1 per cent strain. The second portion has a compressed scale and shows the true-stress and true-strain relation to fracture. Strain measurements, for the first portion, were made with a Tinius Olsen gage accurate to 0.0001 in. in a 2-in. gage length. True stress-strain values were based on instantaneous diameter readings.

TABLE III.—MECHANICAL PROPERTIES OF TITANIUM.

Carbon electrode process, cold drawn and annealed, equal to RC-55 alloy.

Property	Heat								
	RIA-125D		RIA-125C	RIA-125B		RIA-120		RIA-122A	RIA-126B
	Specimen								
	B-33	B-55	T-3	P-1	O-15	UU-28	RR-3	H-33	JJ-28
Proportional limit, psi	55 000	56 000	59 000	61 000	65 000	50 000	51 000	64 000	50 000
Modulus of elasticity, psi × 10^{-6}	17	16	15.0	15.6	15.0	17.3	15.3	15.0	15.5
Yield strength (0.2 per cent offset), psi	75 000	71 500	76 000	71 000	77 500	63 000	69 000	74 000	62 000
Nominal ultimate stress, psi	94 200	91 700	96 500	90 000	93 000	85 000	91 500	90 800	83 000
True ultimate stress at fracture, psi	141 000	133 500	144 000	132 000	132 500	126 000	130 000	126 000	120 000
Per cent elongation at fracture (2-in. gage length)	22.5	24.2	25.0	25.0	27.3	29.6	23.4	24.2	28.1
Per cent reduction of area at fracture	45.6	45.4	47.2	50.4	46.0	48.5	47.5	42.5	49.0
Impact by Charpy V-notch, ft-lb	5.4		...	6.3		...	...	6.2	6.5
Hardness, Rockwell C	23.0	23.4	22.0	28.9	25.9	20.2	20.9	25.3	16.4
Fatigue strength at 10^7 cycles, psi (1800 rpm without coolant)	58 000		55 000	60 000		58 000		...	55 000

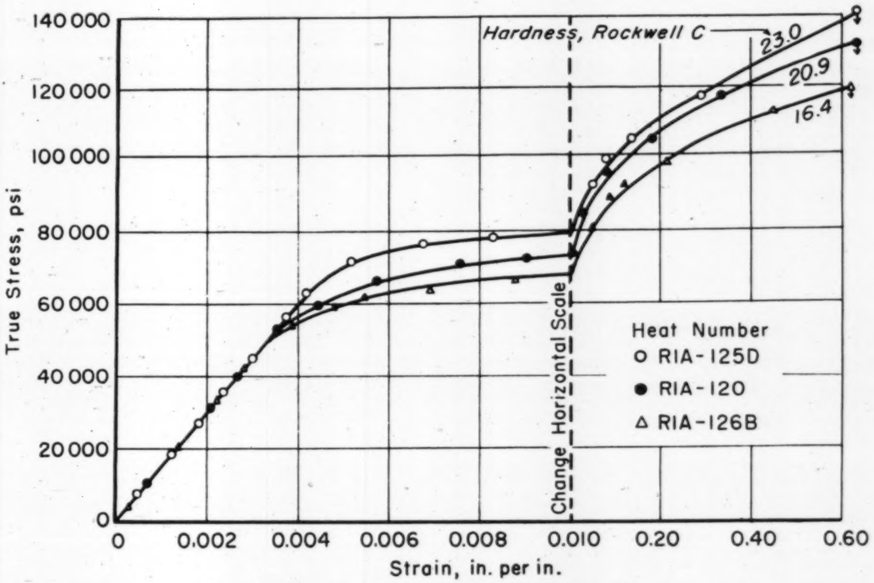

FIG. 1.—Tension Tests of RC-55 Titanium Alloy.

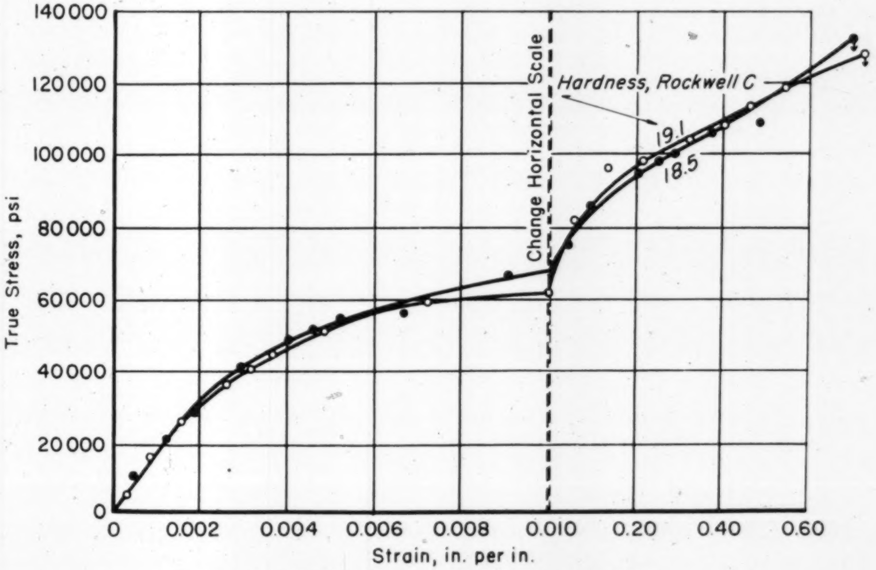

FIG. 2.—Tension Tests of Ti-75A Titanium Alloy.

TABLE III.—MECHANICAL PROPERTIES OF TITANIUM.

Carbon electrode process, cold drawn and annealed, equal to RC-55 alloy.

Property	Heat								
	RIA-125D		RIA-125C	RIA-125B		RIA-120		RIA-122A	RIA-126B
	Specimen								
	B-33	B-55	T-3	P-1	O-15	UU-28	RR-3	H-33	JJ-28
Proportional limit, psi	55 000	56 000	59 000	61 000	65 000	50 000	51 000	64 000	50 000
Modulus of elasticity, psi × 10^{-6}	17	16	15.0	15.6	15.0	17.3	15.3	15.0	15.5
Yield strength (0.2 per cent offset), psi	75 000	71 500	76 000	71 000	77 500	63 000	69 000	74 000	62 000
Nominal ultimate stress, psi	94 200	91 700	96 500	90 000	93 000	85 000	91 500	90 800	83 000
True ultimate stress at fracture, psi	141 000	133 500	144 000	132 000	132 500	126 000	130 000	126 000	120 000
Per cent elongation at fracture (2-in. gage length)	22.5	24.2	25.0	25.0	27.3	29.6	23.4	24.2	28.1
Per cent reduction of area at fracture	45.6	45.4	47.2	50.4	46.0	48.5	47.5	42.5	49.0
Impact by Charpy V-notch, ft-lb	5.4		...	6.3		...	...	6.2	6.5
Hardness, Rockwell C	23.0	23.4	22.0	28.9	25.9	20.2	20.9	25.3	16.4
Fatigue strength at 10^7 cycles, psi (1800 rpm without coolant)	58 000		55 000	60 000		58 000		...	55 000

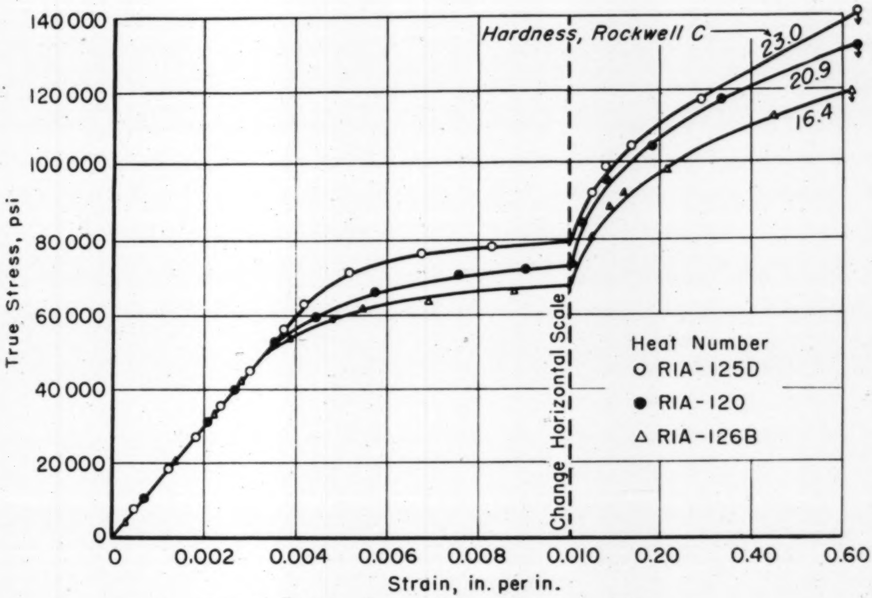

FIG. 1.—Tension Tests of RC-55 Titanium Alloy.

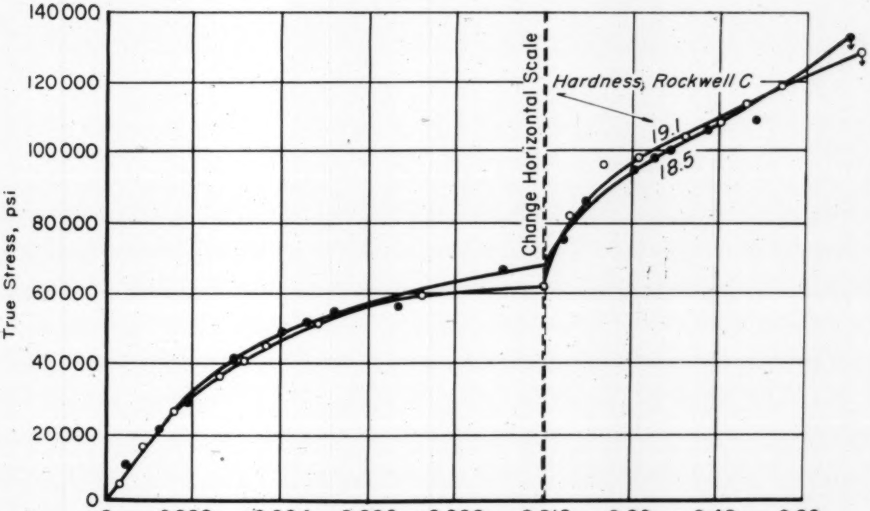

FIG. 2.—Tension Tests of Ti-75A Titanium Alloy.

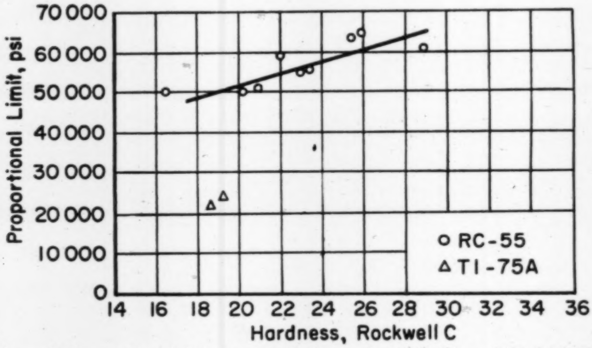

FIG. 3.—Relation of Proportional Limit to Hardness for RC-55 and Ti-75A Titanium Alloys.

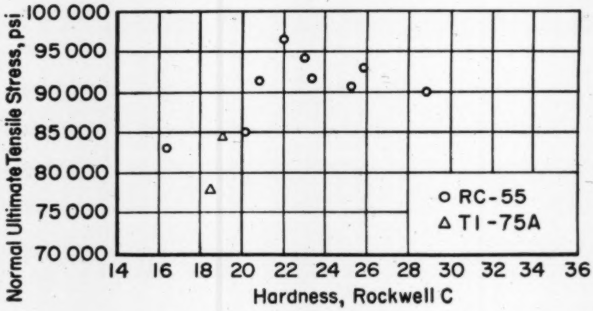

FIG. 4.—Relation of Nominal Ultimate Tensile Stress to Hardness for RC-55 and Ti-75A Titanium Alloys.

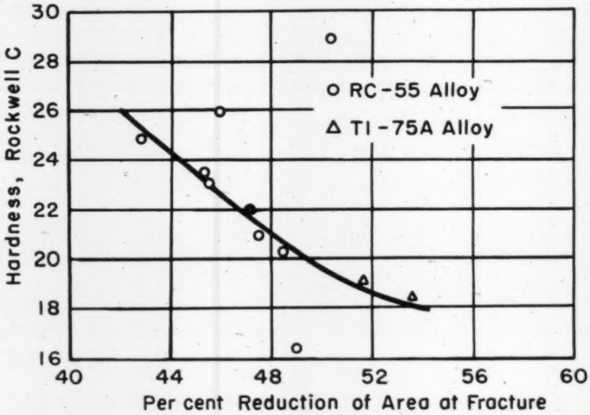

FIG. 5.—Relation Between Per Cent Reduction of Area at Fracture and Hardness for RC-55 and Ti-75A Titanium Alloys.

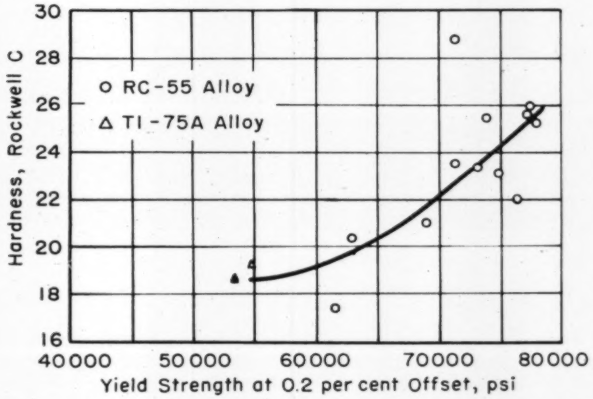

FIG. 6.—Relation Between Yield Strength at 0.2 per cent Offset and Hardness for RC-55 and Ti-75A Titanium Alloys.

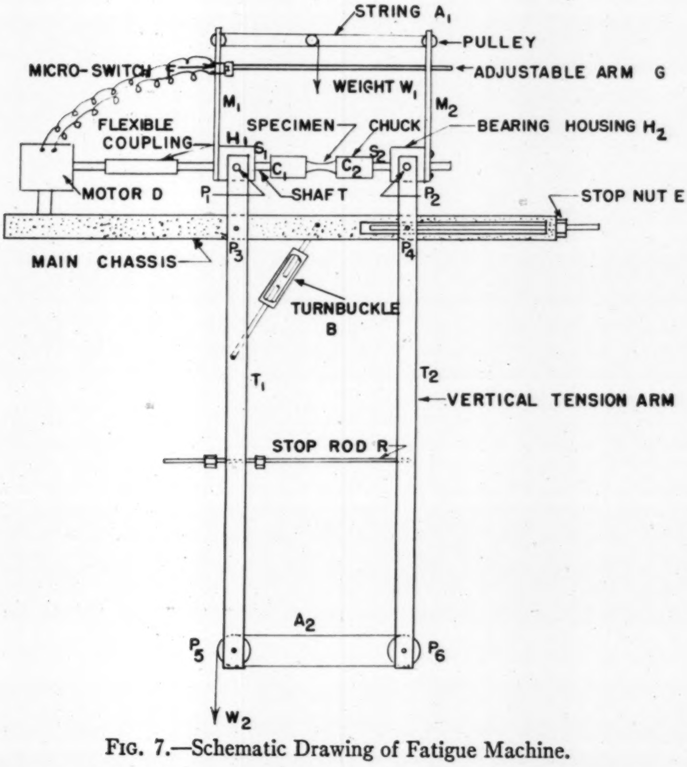
STRING A₁
PULLEY
MICRO-SWITCH F
ADJUSTABLE ARM G
WEIGHT W₁
M₁
M₂
FLEXIBLE COUPLING
SPECIMEN
CHUCK
BEARING HOUSING H₂
H₁
S₁
S₂
C₁
C₂
MOTOR D
P₁
SHAFT
P₂
STOP NUT E
MAIN CHASSIS
P₃
P₄
TURNBUCKLE B
T₁
T₂
VERTICAL TENSION ARM
STOP ROD R
A₂
P₅
P₆
W₂

FIG. 7.—Schematic Drawing of Fatigue Machine.

The curves of Fig. 1 were selected to show the effect of chemical composition. Specimen B-33 (listed in Table III) of heat RIA-125D, which has a low carbon (0.140 per cent) and nitrogen (0.035 per cent) content, showed a high true ultimate stress at fracture (141,000 psi). Specimen JJ-28 of heat RIA-126B, which has a high carbon (0.185 per cent) and nitrogen (0.059 per cent) content, had a low true ultimate stress at fracture (83,000 psi). Specimen RR-3 of heat RIA-120 has intermediary strength properties between those of specimens B-33 and JJ-28.

The RC-55 alloys in Table III are arranged roughly in order of decreasing strength. For purposes of comparison, the listing of the alloys in Table I conforms to that of Table III. The tabulated data indicate a decrease in strength with increase in nitrogen content. The same trend seems to exist with carbon content.

Figures 3, 4, 5, and 6 correlate the strength properties of RC-55 and Ti-75A titanium alloy to Rockwell C hardness. Normally, good correlation is found between hardness and nominal ultimate stress. However, Fig. 4 indicates that this is not the case for the RC-55 titanium alloys. Rather, fair correlation was found between Rockwell C hardness and proportional limit (Fig. 3), and per cent reduction in area at fracture (Fig. 5), and yield strength at 0.2 per cent offset (Fig. 6). (Additional data for RC-55 titanium alloys not summarized in Table III were used in plotting Figs. 3, 4, 5, and 6.) The tabulated and plotted data for the RC-55 titanium alloys indicate a decrease in strength and hardness and an increase in ductility with increase in percentage carbon and nitrogen content.

The few data available for Ti-75A titanium alloy are presented for comparison with those of the RC-55 titanium alloy. Mechanical properties are summarized in Table II.

FATIGUE MACHINES

Fatigue tests were conducted at 1800 rpm on rotating-beam machines designed and constructed in the Department of Civil Engineering at Carnegie Institute of Technology (**4**). These machines are, in all essentials, similar to an earlier machine designed and built by Chao-Lin-Chang (**5**). (See Fig. 7.) Axial and bending stresses are induced in the specimen. Alternating stresses, varying from complete reversal to pure tension, can be developed by varying the magnitudes of the axial and bending stresses.

The specimen is bent by the weight W_1 that is connected by the string A_1 to the vertical moment arms M_1 and M_2. These vertical arms are fastened to the bearing housings H_1 and H_2. Since the housings are free to rotate about the horizontal pivots P_1 and P_2, the bending moment due to the weight W_1 is resisted solely by the specimen.

The specimen is stretched by the weight W_2. The pull in the cable A_2 is resisted by tension in the specimen because the bar T_2 is free to rotate about the pivot P_4.

The machines were calibrated statically and dynamically. Results of dynamic tests showed that the maximum stress was the same whether the specimen was stationary or rotating at 1800 rpm.

FATIGUE SPECIMENS

The fatigue specimens tested at 1800 rpm were 0.25 in. in diameter at the smallest section and 3.00 in. long. The center of the specimens had a radius of 4.53 in. The cutting tool for turning down the radius on the specimen was driven by an auxiliary motor at a uniform speed of 1.2 in. per min along the specimen. The specimen was turned in a lathe at 420 rpm. During the roughing down of the specimen, each pass with the cutting tool was taken at a depth of about 0.032 in. The final two or three cuts were about 0.003 in. each. The specimens were then polished in the circumferential direction with Nos. 1 and 0 emery polishing paper. The final polishing was done with a rouged buffing wheel. The cutting and polishing operation was standardized to obtain a uniform end product.

Specimens tested at 10,000 rpm were standard R. R. Moore fatigue specimens with a minimum diameter of 0.225 in. Specimens had a center radius of 4.53 in. and an over-all length of 3 in.

TABLE IV.—BASIS FOR SELECTION OF FATIGUE SPECIMENS.

Heat[a]	Carbon, per cent	Nitrogen, per cent	Proportional Limit[b], psi	Yield Strength 0.2 per cent Offset[b], psi	Nominal Ultimate Stress[b], psi	True Ultimate Stress at Fracture[b], psi	Hardness, Rockwell C
RIA-125D	0.140	0.035	55 500	73 300	93 000	137 300	20 to 23
RIA-120	0.146	0.045	50 500	66 000	88 300	128 000	20 to 23
RIA-125B	0.180	0.050	63 000	74 300	91 500	132 300	25 to 29
RIA-126B	0.185	0.059	50 000	62 000	83 000	120 000	15 to 17

[a] Taken from Table I.

[b] Average values based on data given in Table III.

TEST PROCEDURE

Complete reversal tests were conducted at 1800 rpm on specimens of the RC-55 alloy, selected from three different hardness ranges. The specimens were also selected on the basis of chemical composition to investigate the effect of carbon and nitrogen content on the fatigue behavior of this alloy. A selection with maximum spread of the strength properties was made in order to allow satisfactory correlation of the static and fatigue properties. Table IV summarizes the chemical composition and average static properties of the four materials tested in fatigue. Specimens from heats RIA-125D and RIA-120 had low carbon and nitrogen contents and relatively similar hardness and strength properties. Those of RIA-125B and RIA-126B had high carbon and nitrogen contents and widely different hardness and strength properties.

Specimens selected from heat RIA-120 with a Rockwell C hardness between 20 and 23 were tested dynamically at 1800 rpm at the following stress ratios[3]: $r = -0.5$, 0, and $+0.2$. When r was greater than $+0.2$, there was a gradual yielding or necking of the specimen before failure instead of a sudden fatigue fracture.

Tests were conducted on specimens prestrained 0.4, 2.0, and 10.0 per cent, a standard tension testing machine being used for prestraining the specimens. Elongations were measured with a pair of ocular micrometers mounted on the fixed head of the machine. A $\frac{3}{4}$-in. gage length was scribed in marking ink and the specimen was pulled a predetermined amount as measured by the optical gages. The increase in length necessary to produce a given prestrain at the smallest section was determined from the stress-strain diagram of the material. To insure alignment, all specimens were machined oversize 0.025 in. before prestraining. After prestraining, the specimens were machined to the proper size and polished.

The fatigue tests described above were conducted at 1800 rpm with the specimens exposed to air. Whenever these specimens were tested above the fatigue strength of 10^7 cycles at complete reversal, their surface temperature increased above the room temperature. The increase in temperature during a test was measured by a thermocouple fastened to the specimen at its smallest section and connected to a strip chart temperature recorder (Leeds & Northrup continous recording potentiometer). The thermocouple was fastened to the specimen by means of a thin piece of wire that did not influence the stress in the specimen. Connections between the thermocouple and the temperature recorder were made by slip rings mounted on the shaft. The leads from the thermocouple were connected to the slip rings, and in turn contact with the leads from the recorder was made through brass brushes.

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[3] Stress ratio, $r = \dfrac{\text{Minimum stress}}{\text{Maximum stress}}$.

The effects of speed of testing and internal heating were studied by testing specimens at different speeds under isothermal and nonisothermal conditions. The surface temperature of the specimen was controlled by spraying with a coolant (water) kept at room temperature. Speeds of 10,000 rpm were obtained with an R. R. Moore high-speed rotating-beam fatigue machine.

Early work by N. E. Promisel (6) on fatigue of titanium showed an endurance limit fairly well developed at 10^7 cycles. Initial tests conducted in this investigation showed a rapid flattening of the *S-N* diagram for number of cycles of stress greater than 5 × 10^6. Repeatedly, specimens tested for 5 × 10^7 cycles of stress near the "endurance limit" did not fail. This has been substantiated by current work being conducted at Carnegie Institute of Technology on five titanium alloys (Ti-150A, RC-130A, RC-130B, Ti-alloy, and Ti-75A) (7), by Bishop, Spretnak, and Fontana (8) and by test results reported in reference (3). Bishop, Spretnak, and Fontana state: "Apparently these alloys (Ti-150A and

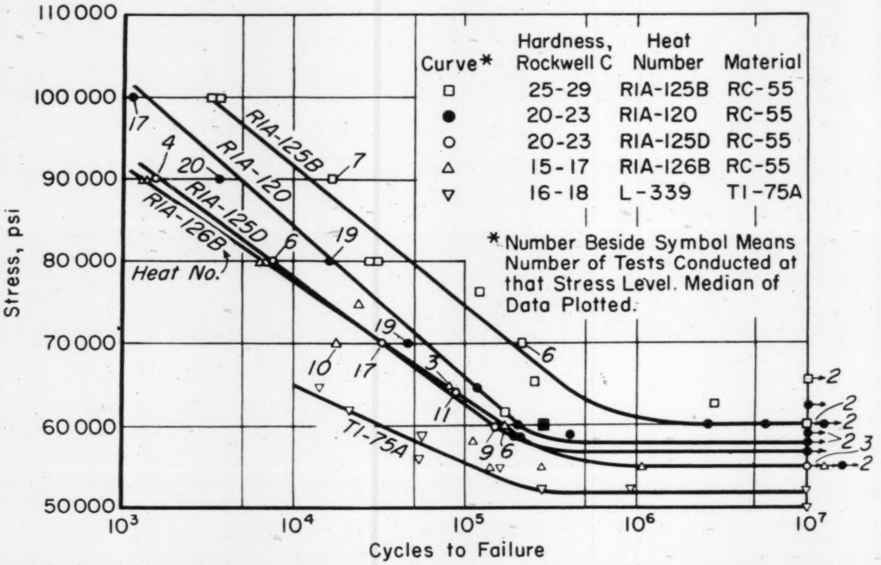

FIG. 8.—*S-N* Diagram for Complete Reversal Tests on Titanium Tested at 1800 rpm Without Coolant.

RC-130B) possess a rather definite endurance limit as shown by the flatness of the S-N curves beyond 10^5 cycles. This is another property they have in common with steels." Since this phase of fatigue behavior of titanium requires further study, fatigue strength at 10^7 cycles is used for correlation of static and dynamic properties of the titanium alloys.

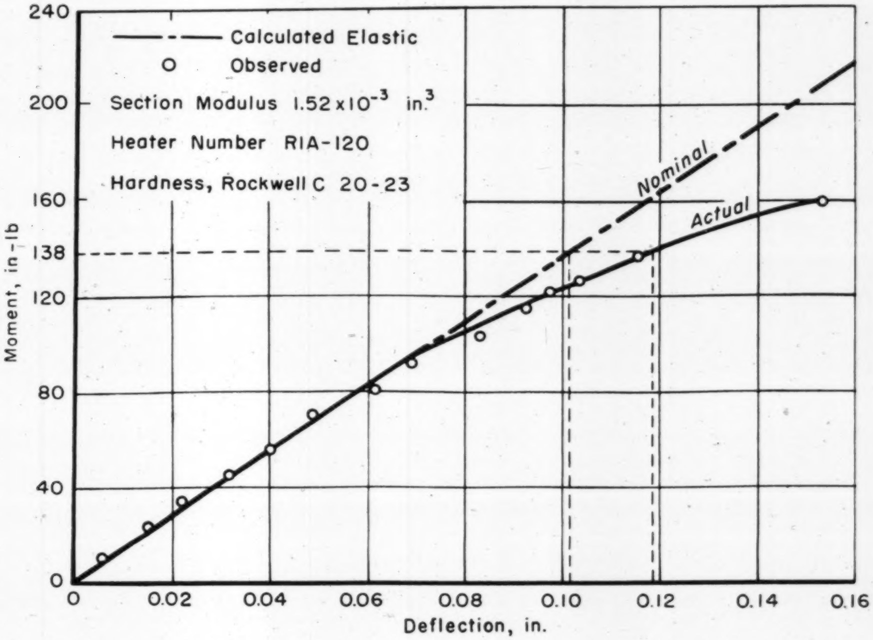

FIG. 9.—Static Deflection at Center of RC-55 Specimen Mounted in Fatigue Machine.

RESULTS OF FATIGUE TESTS

Complete Reversal:

The results of complete reversal tests for five different titanium alloys are shown in Fig. 8. A number beside a point gives the number of specimens tested at a particular stress level. No number implies one test. A point with a number represents the median[4] of the observed data. Detailed data can be found in reference (2).

The scatter of points near the fatigue strength of 10^7 cycles is characteristic for titanium. There is a range of stress for RC-55 and Ti-75A titanium alloys between 60 and 66 per cent of the nominal ultimate stress, where a specimen may fail in a limited number of cycles or may last indefinitely. This same phenomena has been reported by others (3).

Test results indicate an improvement in the fatigue properties of titanium at higher hardness. However, comparison between curves RIA-126B for RC-55 and Ti-75A shows that the relationship is not consistent for both alloys. The Ti-75A alloy has less favorable fatigue properties than the RC-55 alloy of lower hardness. Curves RIA-120 and RIA-125D are results of tests conducted on titanium specimens with the same hardness range and with similar chemical composition (low carbon and nitrogen contents). The two materials have the same fatigue strength at 10^7 cycles but exhibit different behavior in the finite-life range of the *S-N* curve. As shown in Table IV, these two materials have relatively similar strength properties. On the other hand, curves RIA-125B and RIA-126B for two materials with similar chemical composition (high carbon and nitrogen contents) but different strength properties have entirely different fatigue characteristics. The data are inconclusive regarding the effect of chemical composition on the fatigue behavior of RC-55 titanium alloy.

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[4] Median is defined as that point on the scale of a frequency distribution below and above which just 50 per cent of the observations occur.

A comparison between the curves in Fig. 8 and the stress-strain diagrams for these materials shown in Figs. 1 and 2 reveals that titanium has a fatigue strength at 10^7 cycles generally above the proportional limit. This implies that if the actual stress at the surface of the specimen is calculated from a static stress-strain relationship it is less than that calculated on a linear stress-strain basis. For example, a 0.25-in. diameter specimen with a section modulus of 1.52×10^{-3} in.^{3} subjected to a moment of 138 in-lb, has a maximum stress at the surface of 92,000 psi calculated from a linear stress-strain curve and 69,000 psi based on the nonlinear curve of Fig. 1. This lower maximum stress, however, exists for only the first few applications of repeated loading. In fact the stress at the surface of a specimen that originally yielded under a load statically applied rises, after a few cycles of stress, to the value that would have occurred had the specimen behaved purely elastically from the start. Evidence of this behavior is found in Figs. 9 and 10. Figure 9 shows the actual and nominal center deflection of a specimen when loaded statically in the fatigue machine. A bending moment of 138 in-lb would produce a static deflection of 0.101 in. if the material behaved elastically. However, due to plastic deformation, the specimen deflected to 0.118 in. under the static bending moment of 138 in-lb.

Figure 10 (a plot taken from a strip chart recorder), however, shows that during the fatigue test the deflection at the center of the specimen, subjected to the same bending moment of 138 in-lb, is 0.10 in. which, as Fig. 9 illustrates, is the value consistent with elastic behavior. These observations indicate that the

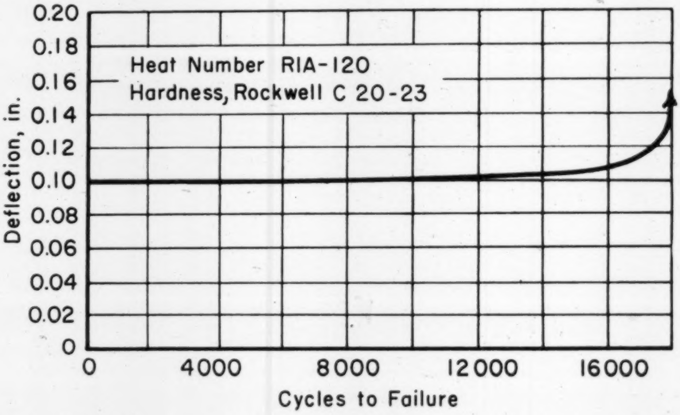

FIG. 10.—Deflection at Center of Specimen Against Number of Cycles, RC-55 Alloy Tested at 1800 rpm Without Coolant (Reproduced from Recording Chart).

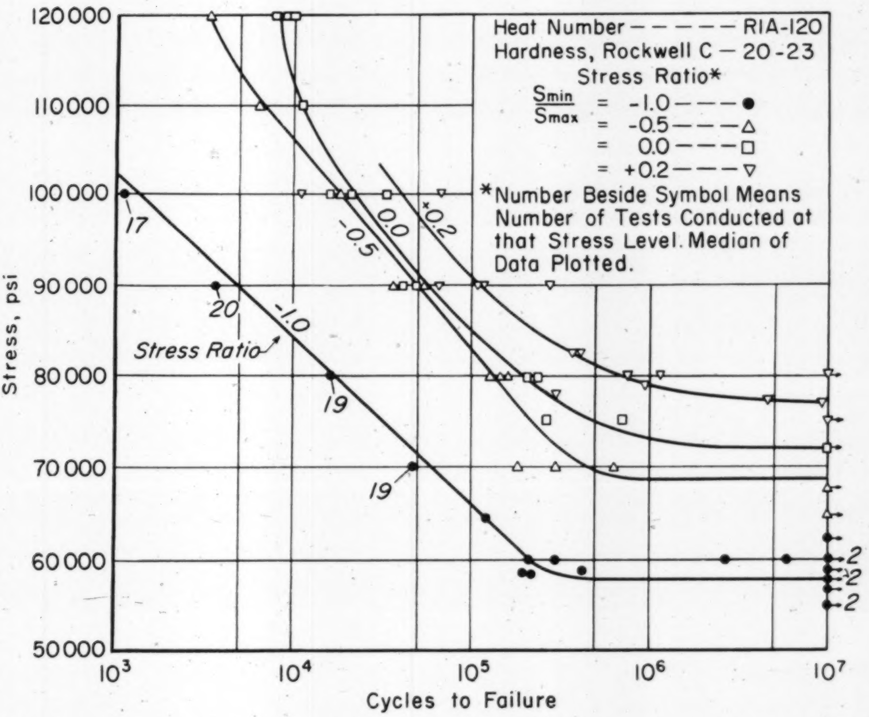

Fig. 11.—*S-N* Diagram for Range of Stress Tests on RC-55 Alloy Tested at 1800 rpm Without Coolant.

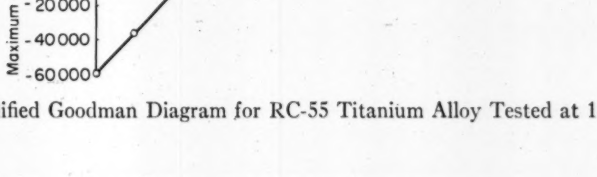

Fig. 12.—Modified Goodman Diagram for RC-55 Titanium Alloy Tested at 1800 rpm Without Coolant.

elastic range of the material is increased due to work hardening. Indeed the specimen did not reach the deflection that would occur considering elastic-plastic behavior until very near fracture. This aspect of fatigue behavior is discussed in reference (9).

Range of Stress:

Range of stress tests for the RC-55 alloy are presented in Fig. 11 for stress ratios of $r = -1.0$, -0.5, 0, and $+0.2$. The maximum stress at 10^7 cycles is significantly increased at high stress ratios. Figure 12, a modified Goodman diagram, shows the relationship between maximum stress at 10^7 cycles and range of stress. The range of stress is assumed to be a linear function of the mean stress.

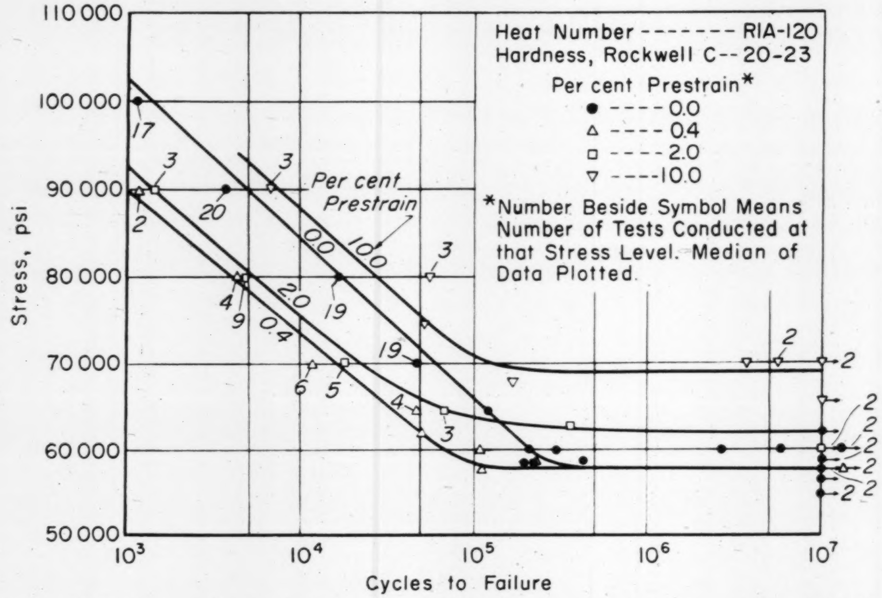

FIG. 13.—*S-N* Diagram for Prestrain Tests on RC-55 Alloy Tested at 1800 rpm Without Coolant.

$$S_a = (\mathrm{EL})_{-1}\left[1 - \frac{S_m}{S_u}\right] \ldots\ldots (1)$$

where:

S_a = alternating stress,

$(\mathrm{EL})_{-1}$ = endurance limit at complete reversal ($r = 1$),

S_m = mean stress, and

S_u = static nominal ultimate stress.

To construct the diagram, the minimum stresses were plotted along a line drawn at 45 deg through the minimum stress complete reversal and the nominal ultimate stress. The experimental points are seen to be slightly above the theoretical values but on the safe side.

Prestrain:

Figure 13 shows the *S-N* diagrams of complete stress reversal tests conducted on prestrained specimens. The fatigue strength at 10^7 cycles for specimens with 0.4 per cent prestrain did not differ from the fatigue strength at 10^7 cycles of specimens not prestrained. However, prestraining the specimens 2.0 and 10.0 per cent considerably increased the fatigue strength at 10^7 cycles. Tests on specimens prestrained 0.4 and 2.0 per cent showed a shorter fatigue life in the finite-life range than specimens with zero prestrain. At 10.0 per cent prestrain the finite-life range of the *S-N* diagram is higher than the *S-N* diagram of the unstrained material. The correlation between per cent prestrain and fatigue strength at 10^7 cycles for specimens tested at 1800 rpm is shown in Fig. 14.

Influence of testing speed and isothermal conditions:

As mentioned earlier, an increase in surface temperature was observed in

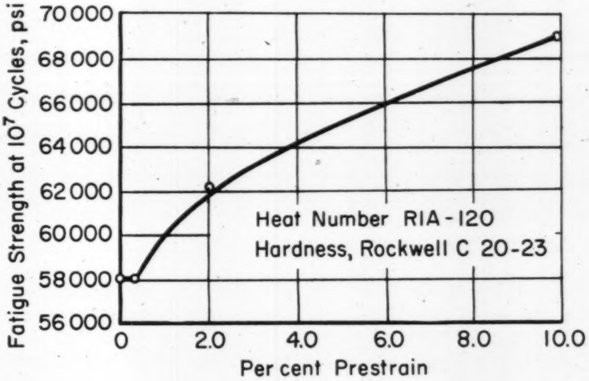

FIG. 14.—Correlation Between Per Cent Prestrain and Fatigue Strength at 10^7 Cycles, RC-55 Alloy. Tested at 1800 rpm Without Coolant.

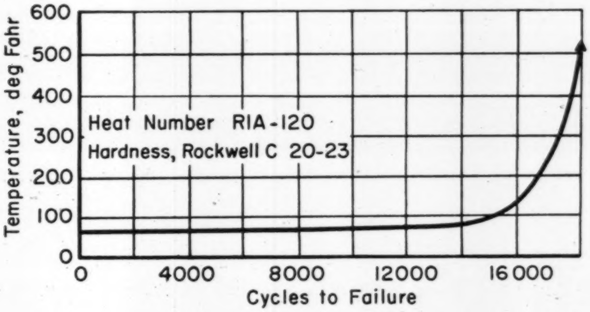

FIG. 15.—Surface Temperature at Center of Specimen *versus* Number of Cycles, RC-55 Alloy. Tested at 1800 rpm Without Coolant (Reproduced from Recording Chart).

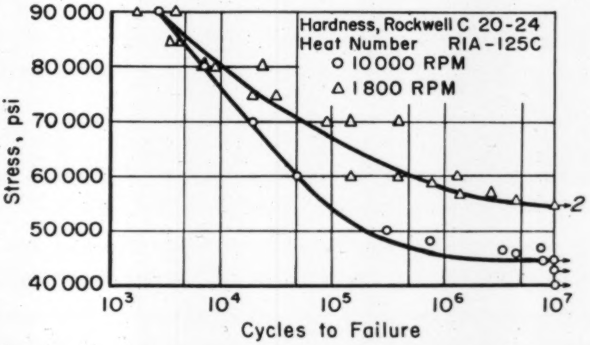

FIG. 16.—Nonisothermal Fatigue Tests at Speeds of 1800 and 10,000 rpm Conducted on RC-55 Alloy.

specimens tested above the fatigue strength at 10^7 cycles and at testing speeds of 1800 rpm without coolant. Figure 15 (a plot taken from a strip chart recorder) shows the surface temperature variation of a specimen tested in complete reversal at a maximum stress of 90,000 psi.[5] This phenomena of surface temperature is also mentioned by Promisel (6).

The question arises as to what effect this temperature rise has on the fatigue life. If the temperature rise has a detrimental effect on the material, failure will be hastened and the fatigue life will be less at a given testing speed and stress level than if the specimen were kept at a constant temperature in the water bath. Furthermore, it would be expected that speed of testing is significant since the faster the testing speed the greater is the heat generated per unit time. This is illustrated in Fig. 16. The tests are nonisothermal and at complete stress reversal. Considering the results of tests conducted at 1800 rpm as base, an increase in the speed of testing from 1800 to 10,000 rpm shows a *decrease* of 11,000 psi in the fatigue strength at 10^7 cycles from 55,000 to 44,000 psi. Figure 17, which gives test results for the same material conducted under isothermal conditions (surface temperature of speci-

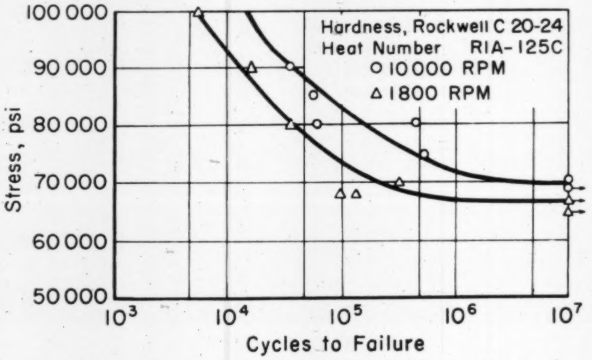

FIG. 17.—Isothermal Fatigue Tests at Speeds of 1800 and 10,000 rpm Conducted on RC-55 Alloy.

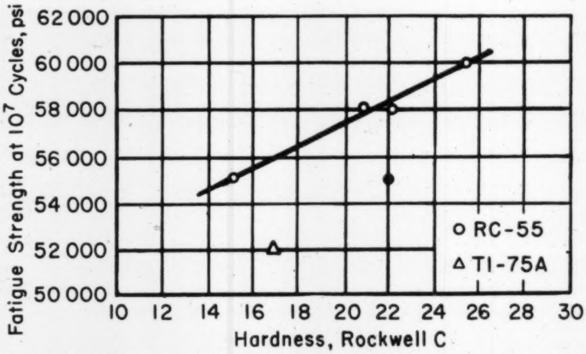

FIG. 18.—Relation Between Fatigue Strength at 10^7 Cycles and Average Hardness.

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[5] The problem of internal heat is more fully discussed in reference (**9**) and is being submitted for publication.

men kept at room temperature by spraying with water), shows for an increase in testing speed from 1800 to 10,000 rpm, an *increase* of 2000 psi in the fatigue strength at 10^7 cycles from 67,000 psi to 69,000 psi. At speeds of 10,000 rpm, the thermal softening caused the fatigue strength at 10^7 cycles to decrease by 25,000 psi, while at 1800 rpm the decrease in fatigue strength at 10^7 cycles was 12,000 psi.

Summary of Deflection and Temperature Observations

The fatigue strength at 10^7 cycles lies above the proportional limit as determined by a static tension test. This indicates that the proportional limit is raised during cyclic stressing. Evidence obtained from deflection tests supports this conjecture. The center deflection of the rotating-beam specimen (Fig. 10) when subjected to cyclic stresses agreed with that calculated from a linear elastic theory. Only upon approaching fracture did the dynamic deflection approach the elastic-plastic deflection observed in a static deflection test.

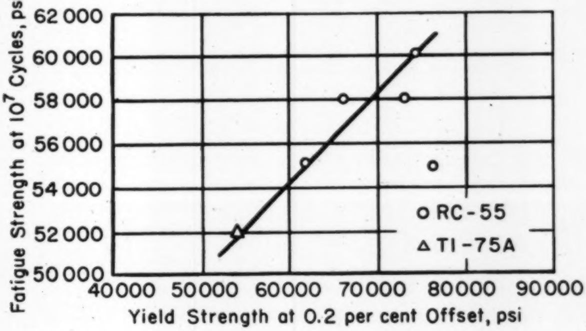

FIG. 19.—Relation Between Fatigue Strength at 10^7 Cycles and Yield Strength.

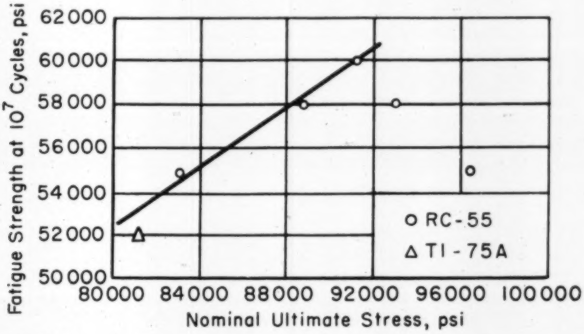

FIG. 20.—Relation Between Fatigue Strength at 10^7 Cycles and Nominal Ultimate Stress.

The elastic behavior continued for about 50 per cent of the number of cycles to failure. In the last 25 per cent of the fatigue life a rapid increase in deflection, as shown in Fig. 10, occurred. The increase in deflection is possibly related to propagation of cracks, work softening, thermal softening, or some combination of these or other factors.

The rate of heat generation in the late life of a specimen is so great that it cannot be conducted away through the specimen or to the surrounding air. Consequently thermal softening and a rapid propagation of cracks and failure follow. Failure is characterized by discoloration and a rough fracture surface. If the heat is carried away by means of a water coolant as fast as it is generated, the strength is not reduced and more work has to be done to produce a fracture. The fractured surfaces of cooled specimens show no distortion. Also, crack propagations extending over roughly one half the area of the specimen have been observed in specimens tested under isothermal conditions (2).

TABLE V.—FATIGUE RATIOS FOR RC-55[a] TESTED AT 1800 AND 10,000 RPM WITH AND WITHOUT COOLANT.

Test Condition	Fatigue Ratios, per cent Testing Speed, rpm	
	1800	10 000
Without coolant	57	47
With coolant[b]	70	73

[a] Heat RIA-125C, Rockwell C Hardness 22 nominal ultimate tensile stress 96,500 psi.

[b] Water sprayed on specimen to maintain normal room temperature at the surface of the specimen.

CORRELATION BETWEEN STATIC AND DYNAMIC PROPERTIES

Figures 18, 19, and 20 give correlations of the static and fatigue properties of RC-55 and Ti-75A titanium alloys. Average values calculated from the data given in Tables II and III were used as the static strength properties. The fatigue strength at 10^7 cycles is based on tests conducted at 1800 rpm and without coolant (that is water was not sprayed on the specimen during cyclic stressing). Figure 18 relates fatigue strength at 10^7 cycles and Rockwell C hardness. Data suggest a straight-line relation for the RC-55 alloy. Figure 19 shows good correlation between fatigue strength at 10^7 cycles and yield strength at 0.2 per cent offset.

Figure 20 gives a fatigue ratio (fatigue strength at 10^7 cycles to nominal ultimate stress) of 65 per cent. This high value has been supported by other investigators (6, 7, 8, 10). It is interesting to consider the effect of internal heating and speed of testing on the fatigue ratio of RC-55 titanium alloy. Table V gives the fatigue ratios obtained from test data plotted in Figs. 16 and 17 and listed in Table III. Controlling the internal heat generated during cyclic stressing significantly increases the fatigue ratio at both testing speeds. This phenomena of internal heating seems to be characteristic of titanium (6, 7, 9) and should be considered in evaluating and comparing fatigue ratios of titanium and its alloys.

CONCLUSIONS

1. Static, tensile strength properties of RC-55 titanium alloy are sensitive to small variations of carbon and nitrogen content. The strength properties appear to decrease and ductility to increase with increase of carbon and nitrogen content.

2. Fair correlation of proportional limit, yield strength at 0.2 per cent offset, and per cent reduction in area at fracture to Rockwell C hardness were found for the RC-55 and Ti-75A titanium alloys, while no correlation was discernible between nominal ultimate tensile stress and Rockwell C hardness.

3. There is good correlation between the fatigue strength at 10^7 cycles and the yield strength at 0.2 per cent offset for RC-55 and Ti-75A titanium alloys.

4. The fatigue ratio (fatigue strength at 10^7 cycles to nominal ultimate tensile stress) ranged from 58 to 66 per cent with an average value of 65 per cent for the two alloys.

5. Speed of testing and cooling of rotating-beam specimens influence the fatigue ratio. Cooling RC-55 titanium alloy during cyclic stressing increased the fatigue ratio 27 and 26 per cent, respectively, at testing speeds of 1800 and 10,000 rpm. The fatigue ratio of specimens tested without coolant *decreased* 10 per cent when tested at speeds of 1800 and 10,000 rpm, while with coolant the fatigue ratio *increased* 3 per cent when tested at the same speeds.

6. The effect of range of stress on the fatigue properties of RC-55 titanium alloy can be predicted by the modified Goodman hypothesis.

7. Tensile prestraining raises the fatigue strength at 10^7 cycles at complete reversal. However, the finite-life range, compared to that of no prestrain, was decreased at prestrains of 0.4 and 2 per cent and was increased at 10 per cent prestrain.

Acknowledgment:

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REFERENCES

(1) C. A. Brophy, B. J. Archer, R. W. Gibson, "Titanium Bibliography 1900–1951," Battelle Memorial Institute, Columbus, Ohio (1952).
(2) J. P. Romualdi and E. D'Appolonia, "The Effects of Range of Stress and Prestrain on the Fatigue Properties of Titanium and Titanium Alloys," Office Chief of Ordnance Research and Development Branch, Watertown Arsenal Laboratory Report No. 401/68–15, Contract No. DA-36-061-ORD-68, Oct., 1952.
(3) "Handbook of Titanium Metal," Titanium Metals Corp. of America, New York, N. Y. (1951).
(4) "A Report on the Construction and Calibration of Two Fatigue Testing Machines," Office Chief of Ordnance Research and Development Branch, Watertown Arsenal Laboratory Report No. 401/68–8, Contract No. DA-36-061-ORD-68, March, 1952.
(5) Chao-Lin Chang, "Effects of Range of Stress and Low Temperature of Fatiguing of Metals—Background and Apparatus," Thesis submitted to the Department of Civil Engineering in partial fulfillment of the requirement of the degree of Doctor of Science, Carnegie Institute of Technology, June, 1952.
(6) "Titanium," Report of Symposium on Titanium, Office of Naval Research, Department of the Navy, Washington, D. C., March, 1949.
(7) J. G. Kaufman, R. G. Crum, E. D'Appolonia, "Correlations of Mechanical Properties of Ti-150A, RC-130A, RC-130B, Ti-Alloy, and Ti-75A Titanium Alloys," Office Chief of Ordnance Research and Development Branch, Watertown Arsenal Laboratory Report No. 401/68–38, Contract No. DA-36-061-ORD-362, April, 1954.
(8) S. M. Bishop, J. W. Spretnak, and M. G. Fontana, "Mechanical Properties including Fatigue of Titanium Base Alloys RC-130B and Ti-150A at very low Temperatures," *Transactions*, Am. Soc. Metals, Vol. 45, p. 993–1008 (1953).
(9) J. P. Romualdi and E. D'Appolonia, "The Effect of Internal Heating on the Fatigue Properties of Titanium," Office Chief of Ordnance Research and Development-Branch, Watertown Arsenal Laboratory Report No. 401/68–28, Contract No. DA-36-061-ORD-259, July, 1953.
(10) J. W. Spretnak, M. G. Fontana, and H. E. Brooks, "Notched and Unnotched Tensile and Fatigue Properties of Ten Engineering Alloys at 25 C and −196 C," *Transactions*, Am. Soc. Metals, Vol. 43, p. 547–570 (1951).

DISCUSSION

MR. GEORGE R. GOHN[1] (*presented in written form*).—The authors are to be congratulated for presenting some very useful data on the fatigue properties of titanium. Such information should prove quite valuable to users of this new material.

Messrs. Romualdi and D'Appolonia have shown a relationship between maximum stress at 10^7 cycles and range of stress for the RC-55 titanium alloy in the form of a modified Goodman diagram, Fig. 11. As stated, the experimental points appear to be slightly above the theoretical values. Reference to the mechanical properties as listed in Table III indicates that this material has an average proportional limit of 50,500 psi and an average yield strength at 0.2 per cent offset of 66,000 psi. The fatigue stress shown for zero mean stress is intermediate between these two values, but the next point shown on the modified Goodman diagram represents a maximum fatigue stress greater than either the proportional limit or the yield strength. In view of this, I do not believe the authors are justified in drawing the conclusion that their test data conform to the modified Goodman diagram. This implies, although the authors do not so state, that the range of stress is dependent upon the mean stress.

W. C. Ellis and the writer, in a paper presented before the Society in 1947,[2] pointed out that a review of the literature indicated that:

1. For ductile materials in torsion the alternating stress was constant for various mean stresses provided the maximum stress did not exceed the yield point.
2. For notch-free ductile specimens in which the mean stress was axial tension, the alternating stress could be computed from the modified Goodman formula.
3. When the mean stress was axial compression, the alternating stress was either constant and equal to or greater than the endurance limit for completely reversed stress.
4. Orowan,[3] on theoretical grounds, had shown that the safe range of stress was independent of the mean stress so long as the maximum stress did not exceed the elastic limit.
5. Gohn and Ellis[2] showed that for two non-ferrous materials tested in bending the range of stress was independent of the mean stress so long as the maximum stress did not exceed the yield point. Subsequently, in a later paper,[4] E. R. Morton and the writer confirmed these observations and further showed that, when the maximum fatigue stress

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[1] Member Technical Staff, Bell Telephone Laboratories, Inc., New York, N. Y.

[2] G. R. Gohn and W. C. Ellis, "The Fatigue Characteristics of Copper-Nickel-Zinc and Phosphor Bronze Strip in Bending Under Conditions of Unsymmetrical Loading," *Proceedings*, Am. Soc. Testing Mats., Vol. 47, p. 713 (1947).

[3] E. Orowan, "Theory of Fatigue Failure," *Proceedings*, Royal Soc., Vol. 171, p. 79 (1939).

[4] G. R. Gohn and E. R. Morton, "A New High-Speed Sheet Metal Fatigue Testing Machine for Unsymmetrical Bending Studies," *Proceedings*, Am. Soc. Testing Mats., Vol. 49, p. 702 (1949).

exceeded the yield strength, the safe range of stress fell off in the direction predicted by the Goodman diagram.

The authors' data would appear to fit more nearly into the findings of Gohn and Ellis and the theoretical prediction of Orowan than into the modified Goodman diagram.

(*Oral discussion*).—There are three points not covered in the written discussion that I would like to mention. About twenty years ago we discussed with H. F. Moore the marked effect of speed on the fatigue characteristics of materials tested in the plastic range. Moore then carried out a number of research projects which confirmed our earlier findings. These are reported in the paper by Ellis and Gohn referred to above.[2] In that paper we showed that the fatigue properties of lead and lead alloys were markedly affected by the speed of testing. For example, there is a ten-fold increase in cycle life when the test is made at 2000 cpm instead of at $\frac{1}{4}$ cpm. Are not some of the authors' results effected by the speed of test since the tests were obviously made in the plastic range?

The second point that I would like to raise with the authors is this: It is known that the modulus of elasticity for nonferrous materials falls off markedly with only slight increases in temperature. Therefore, are not some of these phenomena which they have observed due to the modulus falling off as the temperature rises? If the temperature rises, the modulus will fall off and there will obviously be some deviation from the straight line.

Finally, the authors have pointed out that certain investigators using air as the coolant had reported 80 per cent for the ratio between fatigue strength and tensile strength of titanium alloys tested at high speeds as compared to the 70 per cent which the authors are reporting for tests run at 1800 cpm with water as the coolant. I wonder if this does not go back to some of the basic work which McAdam did when he was at the Naval Engineering Experiment Station. In his work he showed that one of the most corrosive mediums, insofar as its effect on fatigue life was concerned, was tap water taken from the river at Annapolis. We ourselves have shown that ordinary tap water, or even distilled water, when applied to lead results in corrosion-fatigue. Perhaps the higher ratio reported by those using air as a coolant may be due to the fact that the use of water as a coolant leads to corrosion with its consequent reduction in fatigue strength. Since corrosion is a time-dependent function, such results as those cited by the authors are not inconsistent.

MR. B. J. LAZAN.[5]—There are two aspects of this paper I would like to discuss briefly; one is the assumption made by the authors that the cyclic stress is linearly related to the cyclic strain, and the second is the matter of specimen heating during fatigue testing. The points to be discussed require the introduction of some experimental data procured recently in the University of Minnesota program on dynamic properties of materials.

The equipment used in the Minnesota work permits the continuous determination of the dynamic modulus of elasticity and damping energy during the course of rotating-beam fatigue tests.[6] Data procured on such equipment on RC-55 titanium, cold worked, which is similar to one of the materials used by the authors, are shown in accompanying Fig. 21. The dynamic modulus of elasticity curves are secant values (ratios of maximum cyclic stress to maximum cyclic strain during a stress cycle) and refer to the average values for a rotating-beam solid specimen

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[5] Professor of Materials Engineering, University of Minnesota, Minneapolis, Minn.

[6] B. J. Lazan, "A Study with New Equipment of the Effects of Fatigue Stress on the Damping Capacity and Elasticity of Mild Steel," *Transactions*, Am. Soc. Metals, Vol. 42, p. 499 (1950).

(all stresses from zero to maximum present). The specific dynamic modulus (that associated with a specific maximum stress or that under uniform axial tension-compression) would display significantly larger reductions than shown in Fig. 21—very approximately three times as large. The damping energies plotted in Fig. 21 are specific values, or those associated with a specific stress; or that energy which would be absorbed if 1 cu in. of metal were under uniform tension-compression stress.[7] It is apparent from Fig. 21 that both the dynamic modulus and damping energy are affected by both stress magnitude and stress history, the dynamic modulus decreasing and the damping energy increasing with number of stress cycles. The damping and elasticity behavior of other titaniums and other metals are summarized elsewhere.[7]

Referring first to the dynamic modulus curves, it may be seen that even though there is relatively little decrease from the initial static value for near virgin material (for example, refer to the "1.3" curve showing the relationship after 20 cycles of stress), there is a fairly substantial reduction after a large number of cycles have been imposed on the test specimen (for example, refer to the "6" curve showing the relationship after 10^6 cycles have been imposed). Thus, at the fatigue limit the average dynamic modulus may be 10 per cent below the initial static value and the specific dynamic modulus (which is more directly related to stress distribution in the bending specimen and the difference between elastic stress and true stress) would be very approximately 30 per cent lower. Thus, the authors' inference that linearity between strain and stress may be assumed under cyclic stress should be qualified. I should like to inquire if the authors continued to measure the deflection at the center of the specimen during

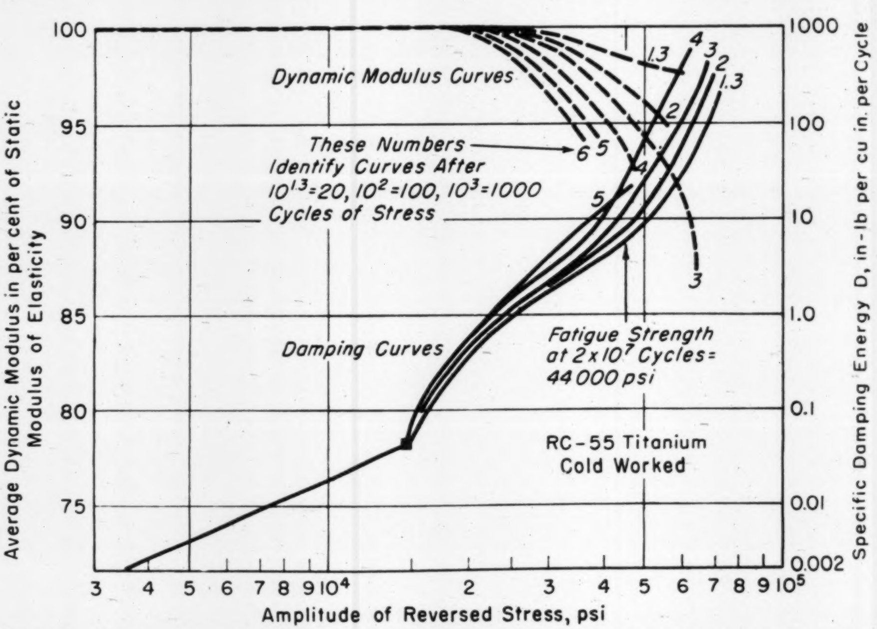

FIG. 21.—Effect of Amplitude of Reversed Stress and Number of Stress Cycles on the Damping and Elasticity Properties of RC-55 Titanium, Cold Worked, at Room Temperature.

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[7] B. J. Lazan, "Fatigue Failure Under Resonant Vibration Conditions," *Technical Report 54-20*, Wright Air Development Center, March, 1954.

the entire fatigue test for RC-55. If so, did they observe any significant increase in deflection under increasing number of cycles at high stress levels?

The second point to be raised is in connection with specimen heating. Such internal heating is directly dependent on the damping energy dissipated by the material as shown in Fig. 21 for RC-55. As may be inferred from the temperature-increase curves shown by the authors, the damping energy does increase significantly with stress history. For example, at the fatigue strength Fig. 21 shows an increase from 6 in-lb per cu in. per cycle for the near virgin material to 20 for the material having 10^5 cycles of stress. This means that 1 cu in. of the material if uniformly stressed under reversed tension-compression would dissipate at the fatigue strength as much as approximately 0.1 hp at 1800 cpm and 0.55 hp at 10,000 cpm (assuming damping not greatly affected by frequency). At a stress of 140 per cent of the fatigue strength, the horsepower dissipated would be roughly ten times the values given above. Needless to say, specimen heating may become a very serious problem in specimens or parts which are stressed so that a reasonably large percentage of the volume of metal is at near peak stress. In parts with severe stress raisers, however, the effective volume of metal at high stress may be a very small percentage of the total volume, and the heat generated by the total damping energy may often be dissipated without serious temperature increases.

In some of the Minnesota attempts to cool fatigue specimens artificially and maintain them at room temperature, some evidence was found that even though the thermocouples and sometimes the surface metal were kept near room temperature, the interior metal still overheated. Did the authors observe any evidence of this in their work?

MR. T. J. DOLAN.[8]—Messrs. Romualdi and D'Appolonia placed emphasis on the proportional limit in interpreting and in commenting on their results. Since the "proportional limit" is markedly influenced by methods of testing, sensitivity of instruments, scale to which data are plotted, and other minor factors, it has little physical significance.

In Fig. 20 showing the relationship between endurance limit and tensile strength, the authors pointed out the endurance limit was roughly 65 per cent of the tensile strength in accordance with the straight line. Since there was considerable scatter of data evident, I am wondering whether this line was faired in at random or determined by the principle of least squares for all of the observations. Several widely divergent values could be obtained for this ratio, depending on how the data were interpreted.

In connection with the temperature rise reported, the figures showing (*a*) deflection increasing with number of cycles and (*b*) increase in temperature with number of cycles were both taken from one specimen. This specimen was tested at a very high stress and the total elapsed time in testing was only about 10 min. At comparable high levels of fatigue stressing, almost every metal exhibits a similar rise in temperature. I should like to ask whether the author has similar data for specimens run at lower stress levels (which lasted for considerably longer periods of time) that show the same trends in temperature rise. Specifically, were temperature records made for all specimens plotted in Figs. 16 and 17?

In Fig. 16 (which showed stress *versus* cycles to failure for tests at 10,000 rpm *versus* 1800 rpm) the curves appear to converge at the upper stress levels. If heating were the only factor it would seem that this is the range in which most heating occurs and for which the data should be most divergent; the dissipation of heat (with more time available) in the slower tests would result in less tendency to overheating than in the 10,000-rpm tests.

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[8] Head of Department of Theoretical and Applied Mechanics, University of Illinois, Urbana, Ill.

Similarly, I would like to emphasize Mr. Gohn's comments about the effect of water on fatigue specimens. Practically all metals have their fatigue life drastically reduced by the simultaneous presence of water on the specimens. While we know little about corrosion-fatigue characteristics of titanium, this could explain the reason why the tests with water as a coolant showed a lower fatigue life at 1800 rpm than at 10,000 rpm. In the slower tests the greater *time* available for corrosion effects could well explain the differences noted in Figs. 16 and 17.

MESSRS. E. D'APPOLONIA AND J. P. ROMUALDI (*authors' closure*).—The authors have reviewed their data on range of stress and concur with Mr. Gohn's statement "... when the maximum fatigue stress exceeded the yield strength the safe range of stress fell off in the direction predicted by the Goodman diagram." We are grateful to him for his comments on range of stress.

Fatigue tests conducted on steel and aluminum alloys indicate that speed of testing does not influence the fatigue behavior. This was not the case with the lead alloys discussed by Mr. Gohn,[2] nor does it apply to titanium alloys. The heat generated during the fatigue testing of steel and aluminum is dissipated almost as rapidly as it is generated. Titanium, however, is a poor heat conductor. The heat that accumulates within the specimen during fatigue testing has an adverse effect on the fatigue behavior of the metal. The modulus of elasticity and other strength properties are decreased because of the heat stored within the specimen. Consequently, the fatigue characteristics of the metal are altered, as shown by Figs. 16 and 17. The detrimental effect of the heat stored is so severe at high stress levels that the fatigue life at 1800 and 10,000 rpm converge. Test data from specimens tested with a coolant do not show this trend.

Tests were not conducted to determine the corrosive effect of a water coolant. Corrosion tests[6] made on commercially pure titanium show that it is completely resistant to attack under all conditions of exposure. Based on these data the authors did not consider corrosion as an important factor in this fatigue study.

Figure 21 given by Mr. Lazan is indeed interesting and is closely related to our work. The authors measured the mid-span deflection of a rotating-beam specimen throughout its entire fatigue life. The deflection of a specimen stressed beyond the linear-elastic range of the material was consistent with the deflection based on an extension of the linear-elastic portion of the load-deflection curve. It was inferred from this observation that stress and strain were linearly related by Young's modulus of elasticity. This pseudo-elastic deflection lasts for only a part of the fatigue life of a specimen. With additional cycles of stress, a rapid increase in deflection and fracture occur. The number of cycles at which the deflection starts to increase depends on the speed of testing and the manner in which the heat generated is dissipated.

Figure 21 shows the decrease in dynamic modulus with increase cycles of stress. We believe this decrease is caused by the heat stored within the specimen during cyclic loading. A thermal softening occurs. If the heat were dissipated as rapidly as it is generated, one would probably not observe the decrease in dynamic modulus with increase cycles of stress as shown in Fig. 21.

The authors did not observe evidence of overheating in the interior of specimens which were cooled during fatigue testing.

With reference to Mr. Dolan's comments, the curve shown in Fig. 20 was faired in at random. The data were not sufficient to justify the use of the method of least squares. A better correlation would not be obtained using this method. The basic assumption usually made with the method—that a normal distribution of the errors exists—is violated by the data of Fig. 20.

Additional data of temperature rise during fatigue testing are available in reference 2. Temperature records were not made for all specimens plotted in Figs. 16 and 17. The tests were conducted either without or with a coolant spray which was maintained at room temperature.

We do not concur with Mr. Dolan that the fatigue data at high stress levels should diverge because of the different rates at which heat is dissipated. At either 1800 or 10,000 rpm the heat generated at high stress levels is so great that it cannot be dissipated without cooling. The thermal softening that occurs at either testing speed tends to produce the same detrimental effect on the fatigue life, with the consequent converging data as indicated in Fig. 20. We have shown from tests conducted on a similar titanium alloy Ti-75A[9] that a divergence of the fatigue life at high stress levels occurs at speeds less than 900 rpm. Above this testing speed specimens not cooled had nearly the same fatigue life at high stress levels.

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[9] R. G. Crum and E. D'Appolonia, "Damage to Titanium under Repeated Load," Office Chief of Ordnance Research and Development Branch, *WAL Report No. 401/68-44*, Contract No. DA-36-061-ORD-362, August, 1954.

A FAILURE CRITERION FOR MULTI-AXIAL FATIGUE STRESSES*

By F. B. Stulen[1] and H. N. Cummings[1]

Synopsis

A criterion or relation is developed for predicting fatigue failure in polycrystalline metals subjected to any combination of steady and vibratory multi-axial stresses. The theory is founded on the assumption that failure is associated with alternating slip on certain critical slip or shear planes and that the critical resolved shear stress governing failure is a linear function of the normal stresses on the critical planes. Methods are proposed to allow for the effect of anisotropy and also for the effect of steady stresses superimposed on the vibratory stresses.

The theory was tested against 270 *S-N* curves, covering vibratory bending or torsion, alone and accompanied by steady bending or torsion, on smooth and on notched specimens, on ductile and on brittle metals. It was compared with the distortion energy theory and with the maximum shear theory, and it consistently gave the best general fit to the test data.

A method of estimating the safety of a part operating under combined biaxial stresses is needed by engineers designing machine parts. The "pure" laws in present use do not accurately apply, unmodified, to all materials. The distortion energy law has been recommended for isotropic ductile material, but it is not reliable for brittle materials such as cast iron. The maximum principal stress law works fairly well for brittle but not for ductile material.

Investigators have long speculated on the possibility that some one of the theories of elastic failure under *static* loads might be applied to failures under fatigue conditions. The "static" theories commonly considered are discussed by Marin (1,[2] p. 47 *et seq.*). In this discussion, Marin transforms the Coulomb theory for static failure into a form (1, p. 60) that is identical with the form $p_{1v} - \lambda p_{3v} = s_e$ (see Appended List of Symbols) proposed herein for fatigue strength. And he states, in effect, that for ductile materials $\lambda = 0.67$ is a good average value. (See values of λ in Table I.) The hypothesis upon which the proposed criterion for fatigue failure is developed is nearly the same as that of Coulomb and also of Mohr. Nadai (2) quotes Mohr as saying, in 1914, "... the shearing stress in the planes of slip reaches at the limit a maximum value dependent on the normal stress acting in the same planes, and on the properties of the material." Nadai discusses the soundness of Mohr's theory as applied to static failure and the "difficulties regarding certain predictions of this theory of strength." Another theory of static failure that the proposed fatigue criterion resembles closely is that proposed by Guest (3) in 1900. With the proper value of the material constant in the Guest law for static failure, it becomes identical with that proposed in this paper. In fact, the proposed criterion, as shown later in this paper, becomes identical, under proper conditions, with one after another of several well-known static criteria. It is proposed not as something particularly new, but as a composite relationship that is simple in form and easy to apply—and reliable, at least in the various fields in which it was checked, to within about 5 per cent. The theory of failure is developed for the case of zero mean (steady) stress only. The empirical procedure to allow for superimposed steady stresses is proposed as a temporary workable method that can be used pending the completion of the extension of the theory to this case.

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[2] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 834.

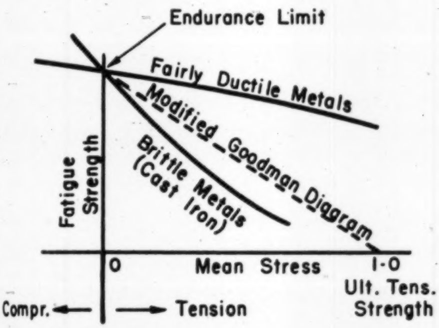

FIG. 1.—Fatigue Strengths of Unnotched Specimens Under Combined Uniaxial Stresses According to Smith (9).

Although there is a vast amount of experimental data on fatigue in the literature today, there does not appear to be any universal criterion governing fatigue failure with the exception, possibly, of the Guest law and the distortion energy law. The distortion energy law of failure is known to agree fairly well with the endurance limits found by biaxial fatigue tests, but it does not appear to be directly related to the mechanism of failure in single crystals where it has been found that the first evidence of distortion is associated with slip on certain fixed critical planes. The slip theory of distortion in single crystals has a certain vectorial connotation, a condition that is lost in any energy criterion of failure. It is thought that a general expression for fatigue failure in polycrystalline metals might be more directly related to the concept of slip in single crystals. The relation of slip to yielding is discussed by many authors (2, 4–8, and others).

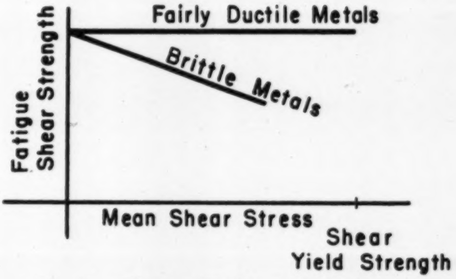

FIG. 2.—Torsion Fatigue Strengths of Unnotched Specimens Under Combined Steady and Alternating Shear Stresses According to Smith (9).

Before stating the hypotheses for the theory developed in this paper, certain commonly known characteristics in fatigue will be reviewed. Some years ago, J. O. Smith (9) compiled the results of a number of investigations of fatigue in the form of simplified Goodman diagrams. The results of his compilation on unnotched specimens are shown in Figs. 1 and 2.

The main feature (Fig. 1) to be noted for the cases of combined steady and alternating uniaxial stresses is that the curve of fatigue strengths of ductile materials as plotted against the mean stress is concave downwards and is fairly flat in the compressive range of the mean stress. On the other hand, brittle metals such as cast irons show curves that are concave upwards and have increasingly higher fatigue strengths with increasing compressive stresses. This indicates that brittle metals are highly dependent on the magnitude of the mean stress whereas ductile materials are only moderately so.

In tests of combined mean and vibratory shear stresses (Fig. 2), Smith noted that the fatigue strengths of ductile materials in shear were approximately independent of the values of the mean shear stress. The torsional fatigue strengths of brittle metals, however, decreased with increase in the mean shear stress but not so rapidly as in the case of uniaxial combined mean and vibratory stresses.

These observations would lead to the suspicion that fatigue strength of polycrystalline metals might be dependent mainly on a critical vibratory shear stress and independent of the steady shear stress on this critical plane. The critical shear stress appears to be modified by the maximum stress normal to the critical shear plane.

The following theory is limited to the condition that approximately the same volume of metal is tested under the various states of stress so that the size effect is not involved. The theory is also limited to sinusoidal variation of stress with time and to the condition that all periodic stresses are synchronous and of the same frequency. The latter limitation is to eliminate the consideration of the speed effect factor.

The development presented in the following paragraphs is based on the following two hypotheses:[3]

1. The fatigue strength of a polycrystalline metal is assumed to be primarily dependent on a critical shear stress in fatigue which, in turn, is linearly dependent on the maximum stress normal to the plane of this critical shear.

2. The fatigue strength is assumed to be independent of the mean shear stress on the critical shear plane.

THEORY

The assumption that the critical shear stress is dependent on the stress normal to the critical shear plane is described graphically in Fig. 3. (This assumption is consistent with the results of Bridgman's tests (**10**) showing that under high hydrostatic compressions the failure strength of metals is measurably increased.)

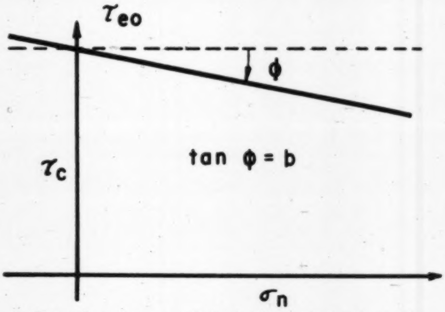

FIG. 3.—Assumed Relation of Critical Shear and Normal Stress.

If the vertical intercept is designated by τ_{e0} and the slope of the line by b (where b is actually negative), the equation relating the critical shear stress linearly to the maximum normal stress is then:

$$\tau_e = \tau_{e0} + b\sigma_n \ldots\ldots\ldots\ldots (1)$$

It has been found that in ductile metals the value of b is near zero, whereas in very brittle metals it is relatively large in the negative sense.

The Mohr circle shown in Fig. 4 is drawn for principal biaxial alternating stresses that are out-of-phase, that is, the maximum principal stress is tension

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[3] The same criterion can be developed by considering that the material is filled with randomly (or preferred) oriented defects such as ellipsoid holes and then computing the maximum stress at the critical defect.

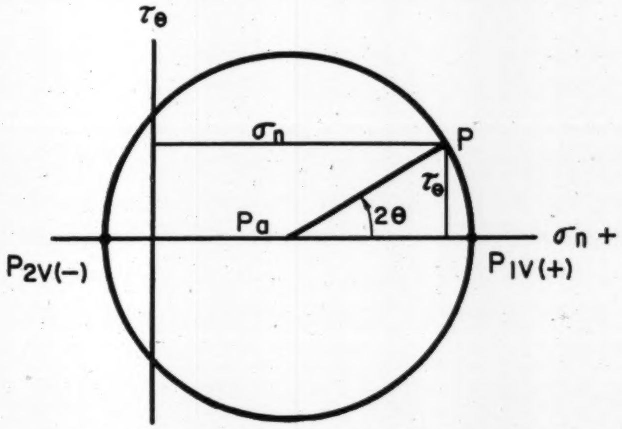

FIG. 4.—Mohr Circle for Out-of-Phase Principal Stresses.

(+) and the minimum is compression (−). The coordinates of point P on the circle represent the shear and the normal stress on any plane whose normal makes an angle θ with the direction of the maximum principal stress.

It can be seen that these stresses are:

$$\left.\begin{aligned}\sigma_n &= p_a + \tau\cos 2\theta\\ \tau_\theta &= \tau\sin 2\theta\end{aligned}\right\}\ldots\ldots\ldots(2)$$

where:

$$p_a \equiv \frac{p_{1v}+p_{2v}}{2};\qquad \tau \equiv \frac{p_{1v}-p_{2v}}{2}\ldots(3)$$

Then by Eqs 1, 2, and 3 the shear on any plane is related to the critical shear as follows:

$$\frac{\tau_\theta}{\tau_c} = \frac{\tau\sin 2\theta}{\tau_{e0} + b(p_a + \tau\cos 2\theta)}\ldots\ldots\ldots\ldots(4)$$

For a given set of values of the principal stresses, the critical plane will be that which has the highest value of the above ratio; it is on such a plane that failure first begins. To find the value of θ for this critical plane, the maximum ratio is obtained by differentiating in respect to θ and equating to zero. This gives:

$$\cos 2\theta = \frac{-b\tau}{\tau_{e0} + bp_a}\ldots\ldots\ldots(5)$$

whence:

$$\sin 2\theta = \frac{\sqrt{(\tau_{e0}+bp_a)^2 - (b\tau)^2}}{\tau_{e0} + bp_a}\ldots(6)$$

On substituting this into Eq 2, the shear stress on the critical plane may then be found. In order that failure occur, this latter shear stress must be equal to the critical value given by Eq 1. On making these substitutions it is found that:

$$\tau = \frac{\tau_{e0} + bp_a}{\sqrt{1+b^2}};\qquad \left(\tau = \frac{p_{1v}-p_{2v}}{2}\right)\ldots(7)$$

or:

$$\frac{p_{1v}-p_{2v}}{2} = \frac{\tau_{e0}}{\sqrt{1+b^2}} + \frac{b}{\sqrt{1+b^2}}\left(\frac{p_{1v}+p_{2v}}{2}\right)\ldots(8)$$

This leads to:

$$p_{1v} - \lambda p_{2v} = S_e\ldots\ldots\ldots(9)^4$$

where:

$$\left.\begin{aligned}\lambda &\equiv \frac{b+\sqrt{1+b^2}}{-b+\sqrt{1+b^2}}\\ &\equiv \left(b+\sqrt{1+b^2}\right)^2\\ S_e &\equiv \frac{2\tau_{e0}}{\sqrt{1+b^2}-b}\\ &\equiv 2\tau_{e0}\left(b+\sqrt{1+b^2}\right)\end{aligned}\right\}\ldots(10)$$

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[4] As pointed out previously Marin (1) derives the equivalent of Eq 9 directly from Coulomb's equations.

Equation 9 is the criterion of fatigue failure when the alternating principal stresses are of opposite signs. The constant in the right member of the equation must be the endurance limit of the material for pure alternating bending or axial loading. The constant, λ, is a constant that is characteristic of the material tested.

In an isotropic material, the constants in Eq 9 may be obtained directly from fatigue tests in pure alternating bending and pure alternating torsion. The right member is simply the endurance limit, s_e, in pure bending. In a pure torsion fatigue test, the principal stresses are equal and opposite and equal to the shear stress. If τ_e designates the endurance limit (or fatigue strength for a fixed number of cycles) for shear, then Eq 9 becomes:

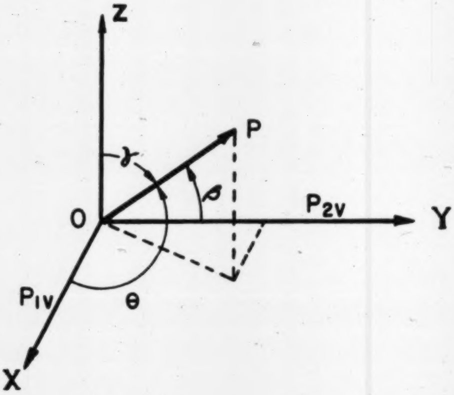

FIG. 5.—Reference Axes for Location of Critical Shear Plane.

$$\tau_e - \lambda(-\tau_e) = S_e \qquad (11)$$

On solving for λ:

$$\lambda = \frac{S_e}{\tau_e} - 1 \qquad (12)$$

This relation gives a simple means of obtaining the parameter λ from experimental data.

By substituting Eq 10 into the above, a relation between τ_e and τ_{e0} is obtained:

$$\tau_e = \frac{\tau_{e0}}{\sqrt{1 + b^2}} \qquad (13)$$

Since b is not usually greater than about 0.5 for ductile metals, little difference between these two shear values (τ_e and τ_{e0}) is involved. The difference is caused by the fact that, in pure shear, the critical shear plane is not exactly the same as that on which the alternating shear is a maximum.

The foregoing analyses are strictly applicable only when one principal stress is opposite in sign to the other when both reach their maximum values in the time cycle. When the biaxial vibratory stresses are of like sign, a different criterion of failure is obtained. The following is a more general analysis for both conditions.

Figure 5 represents an orthogonal system; the directions of the axes are so chosen that the major principal stress vector is along the OX-axis and the minor principal stress vector is along the OY-axis. In the previous paragraphs the shear planes considered are those whose normals are in the XOY plane. In the following analysis, shear planes whose normals have all possible directions in space will be investigated. A normal to one of the shear planes is represented by the unit vector, OP, in Fig. 5. This vector has the directional angles β, θ, and γ.

The magnitude of the shear stress on this plane, as caused by the two principal cyclic stresses, p_{1v} and p_{2v}, can be shown to be:

$$\tau_\theta = \left\{ \left(\frac{p_{1v}}{2}\right)^2 \sin^2 2\theta - 2p_{1v}\, p_{2v} \cos^2\theta \cos^2\beta + \left(\frac{p_{2v}}{2}\right)^2 \sin^2 2\beta \right\}^{1/2} \qquad (14)$$

Also the stress normal to this plane is:

$$\sigma_n = p_{1v} \cos^2\theta + p_{2v} \cos^2\beta \qquad (15)$$

The ratio between the shear stress of

Eq 14 and the critical shear stress of Eq 1 is:

$$R = \frac{\tau_\theta}{\tau_c} = \frac{\left\{\left(\frac{p_{1v}}{2}\right)^2 \sin^2 2\theta - 2p_{1v}p_{2v}\cos^2\theta \cdot \cos^2\beta + \left(\frac{p_{2v}}{2}\right)^2 \sin^2 2\beta\right\}^{1/2}}{\tau_{e0} + b(p_{1v}\cos^2\theta + p_{2v}\cos^2\beta)} \quad (16)$$

The maximum value of this ratio will result in the selection of that shear plane which is most critical. The conditions for the maximum value of this ratio are:

Condition 1:

When p_{1v} is opposite in sign to p_{2v}:

$$\cos 2\theta = \frac{-b\tau}{\tau_{e0} + bp_a}; \qquad \gamma = 90 \text{ deg.} \ldots\ldots (17)$$

(Same as Eq 5)

Condition 2:

When p_{1v} and p_{2v} have the same sign ($p_{1v} > p_{2v}$):

$$\cos 2\theta = \frac{-(bp_{1v}/2)}{\tau_{e0} + (bp_{1v}/2)}; \qquad \beta = 90 \text{ deg.}\ldots (18)$$

The first condition has already been developed and is the condition of failure when the biaxial alternating principal stresses are of opposite sign. It is seen from condition 2 that when these two stresses are of like sign, the normal of the critical shear plane is in the XOZ plane and only the maximum principal alternating stress governs the failure. When these values of θ and β are substituted into Eqs 14 and 15, and these latter equations are substituted into Eq 1, the following relation is obtained:

$$\left(\frac{p_{1v}}{2}\right)^2 = \tau_{e0}^2 + \tau_{e0}\, bp_{1v} \ldots\ldots (19)$$

On reducing this relation it is found that the solution is simply:

$$p_{1v} = 2\tau_{e0}\left(b + \sqrt{1 + b^2}\right) = S_e \ldots\ldots (20)$$

(Same as Eq 10)

In other words, when the applied vibratory principal stresses are of like sign, the relation for failure reduces to the maximum principal stress.

To summarize, Eqs 9 and 20 are the criteria of fatigue failure for biaxial stresses, the steady or mean principal stresses being zero.

Equations 9 and 20 may be replaced by a single relation in the following manner: Since there are three principal stresses that are mutually orthogonal (although one or two of the three may be zero), the stresses may be ordered so that the greatest is equal to p_{1v} and the algebraic least is equal to p_{3v}.

Using this convention, the general relation now becomes:

$$p_{1v} - \lambda p_{3v} = S_e \ldots\ldots\ldots\ldots (21)$$

Relation to Older Criteria:

Equation 21 is seen to be the same as or similar to one or another of the older classical laws of failure, depending on the value of the parameter, λ. The various laws and associated values of the parameter are listed in the following tabulation. The identities are algebraically exact for particular values of λ as noted, except in the case of the distortion energy law where the relation is only approximate. (Some of the classical laws are discussed by Findley 11.)

Criterion	Condition	λ
(1) Maximum principal stress law	Biaxial and triaxial stresses	0
(2) Maximum shear stress law	Biaxial and triaxial stresses	1
(3) Maximum principal strain law	Biaxial out-of-phase stresses	= Poisson's ratio
(4) Gough's elliptic quadrant law	Combined torsion and bending[a]	1
(5) Gough's elliptic arc law	Combined torsion and bending[a]	$0 < \lambda < 1$
(6) Guest's law[b]	Biaxial and triaxial stresses	A constant
(7) Distortion energy	Biaxial stresses	Approximately 0.7

[a] For explanation of these criteria, see reference (12).

[b] When Guest's "material constant" = $[(2\tau_e/s_e) - 1]$, Guest's law is the same as Gough's elliptic arc law (see reference (12)).

TABLE I.—SUMMARY OF RESULTS OBTAINED BY APPLICATION OF THE PROPOSED CRITERION TO VARIOUSTESTS.

Item	Reference	Material	Type of Loading	Test Speed, cycles per min	Type of Specimen	Number of S-N Curves	Life Cycles	λ_θ for θ-0 deg	Steady Stress Effect $(a + mp_{1m})$(Eq 32)	Standard Deviation σ_d, per cent: Proposed Criterion	Standard Deviation σ_d, per cent: Distortion Energy	Standard Deviation σ_d, per cent: Maximum Shear
1....	11	Aluminum Alloy 76S-T61 73 ksi, ult.[a]	Vibratory plus steady bending and torsion	1750(?)	Smooth, solid, round	16	10^4	0.62	$1.039-0.0063\ p_{1m}$	5.1		
2....	11						10^5	0.58	$1.040-0.0086\ p_{1m}$	4.6		
3....	11						10^6	0.52	$1.012-0.0072\ p_{1m}$	5.5		
4....	11						10^7	0.58	$0.999-0.0052\ p_{1m}$	4.7		
5....	11						10^8	0.55	$0.994-0.0039\ p_{1m}$	4.4	5.8	3.7[b]
6....	12	Steel, nickel-chromium-molybdenum 145 ksi, ult.		2130		29	10^7	0.58	$1.031-0.0022\ p_{1m}$	5.4	5.8	3.8[b]
7....	12				Notched, hollow, round—small radial hole	14		0.44	$1.018-0.0022\ p_{1m}$	3.8		
8....	12				Notched, hollow, round—sharp transition fillet	14		0.28	$1.043-0.0022\ p_{1m}$	5.1		
9....	12				Notched, hollow, round—6 longitudinal splines	14		2.05	$1.004-0.0015\ p_{1m}$	4.0		6.0[b]
10....	12	Steel, 0.1 per cent carbon Normalized 63 ksi, ult.	Vibratory only—bending and torsion		Smooth, solid, round	7		0.77		2.7	2.4	8.5
11....	12	Steel, 0.4 per cent carbon Normalized 94 ksi, ult.				7		0.60		1.7	1.8	12.3
12....	12	Steel, 0.4 per cent carbon Spheroidized 70 ksi, ult.				7		0.76		2.9	2.6	7.9
13....	12	Steel, 0.9 per cent carbon Pearlitic 123 ksi, ult.				7		0.46		2.8	9.2	16.2 3.1[b]
14....	12	Steel, 3 per cent nickel 76 ksi, ult.				7		0.67		3.1	5.1	10.6
15....	12	Steel, 3 to 3½ per cent nickel 105 ksi, ult.				7		0.66		2.0	5.0	11.3

16....	12	Steel, chromium-vanadium 110 ksi, ult.	Vibratory only—bending and torsion	2130	Smooth, solid, round	7	10^7	0.66		3.4	5.3	11.9
17....	12	Steel, 3½ per cent nickel-chromium Normal impact 130 ksi, ult.				7		0.54		4.2	7.7	15.3
18....	12	Steel, 3½ per cent nickel-chromium Low impact 130 ksi, ult.				7		0.57		4.4	7.4	14.4
19....	12	Steel, nickel-chromium-molybdenum (Same as items 6–9) 145 ksi, ult.				7		0.78		4.7	3.9	9.8
20....	12	Steel, nickel-chromium 242 ksi, ult.				7		0.71		3.5	3.7	8.3 2.7[b]
21....	12	Steel, nickel-chromium-molybdenum 181 ksi, ult.				7		0.93		5.1	3.3	7.4
22....	12	Cast iron Silal 34 ksi, ult. (tensile)				7		0.10		2.1	19.8	28.0 5.7[b]
23....	12	Cast iron Nicrosilal 34 ksi, ult. (tensile)				7		0.20		3.5	16.2	23.9 4.5[b]
24....	12	Steel, 0.4 per cent carbon Normalized (Same as item 11)				7		0.02		0.7	26.0	4.6[b]
25....	12	Steel, 3 per cent nickel (Same as item 14)			Notched, solid, round sharp V-notch	7		0.39		2.1	9.8	
26....	12	Steel, 3 to 3½ per cent nickel (Same as item 15)				7		0.65		2.9	3.8	
27....	12	Steel, chromium-vanadium (Same as item 16)				7		0.35		3.1	10.4	
28....	12	Steel, 3½ per cent nickel-chromium Normal impact (Same as item 17)				7		0.14		4.5	15.8	7.3[b]

(Continued on p. 830)

TABLE I.—*Concluded.*

Item	Reference	Material	Type of Loading	Test Speed, cycles per min	Type of Specimen	Number of *S-N* Curves	Life Cycles	λ_θ for θ-0 deg	Steady Stress Effect $(a + mp_{1m})$(Eq 32)	Standard Deviation σ_d, per cent		
										Proposed Criterion	Distortion Energy	Maximum Shear
29....	12	Steel, 3½ per cent nickel-chromium Low impact (Same as item 18)	Vibratory only—bending and torsion	2130	Notched, solid, round sharp V-notch	7	10^7	0.36		5.6	13.3	
30....	12	Steel, nickel-chromium-molybdenum (Same as item 21)	Vibratory only—bending and torsion	2130	Notched, solid, round sharp V-notch	7	10^7	0.13		3.4	17.5	5.5[b]
31....	13	Steel, SAE 1020 62 ksi, ult.	Pulsating—longitudinal tension or compression—tangential tension	880	Smooth, hollow, round	4	10^7	0.6		5.4	7.6	8.6 17.0[b]
32....	15	Aluminum alloy 14S-T 72 ksi, ult.	Pulsating—longitudinal tension or compression—tangential tension	1800	Smooth, solid, round	10	10^7	1.07	$0.996–0.0064\ p_{1m}$	3.5	6.3	3.9[b]
33....	16	"Mild Steel"	Vibratory—bending and torsion	2130(?)	Smooth, solid, square	22	2 (10^5) to 6.2 (10^6)	Predicted position of cracks precisely				

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[a] Thousands of pounds (kips) per square inch.

[b] Maximum shear "corrected for anisotropy" as suggested by Findley (11).

Since λ is a constant that is characteristic of the material and that may have a theoretical value between zero and unity, it is not surprising that so many criteria have been proposed in the past.

Effect of Notches

Although the reason is not clear at the present time, it has been found that Eq 21 is valid for any type of notch subjected to combined biaxial stresses. In this case the principal stresses are the *nominal* values without inclusion of the notch reduction factors. However, the value of s_e depends on the type of notch as does the value of λ. The criterion for failure of notches under biaxial fatigue stresses is then:

$$p_{1v} - \lambda_N p_{3v} = s_{eN} \qquad (22)$$

and

$$\lambda_N = \frac{S_{eN}}{\tau_{eN}} - 1 \qquad (23)$$

where:

s_{eN} = endurance limit for notched material as a nominal stress for the case of uniaxial (bending) stress, and

τ_{eN} = endurance limit for the same notch as a nominal stress for the case of pure torsion.

If the notch reduction factors are known for the bending and torsion cases, then both s_{eN} and τ_{eN} may be directly computed.

Modification for Anisotropy

In the foregoing theory, it has been assumed that the material is isotropic. Fatigue tests have in general shown that there is a difference between the longitudinal and transverse endurance limits. That in the direction of forging, rolling, or extrusion is usually higher than that in transverse directions. There is very little information in the literature upon which to formulate a mathematical expression for the variation of endurance limits as specimens, formed at an angle θ with the "longitudinal" direction, are tested. Since the few tests available indicate that probably the anisotropy effect on endurance limits, while appreciable, is not large, it was decided to use the cut-and-try method and indicate by the subscript θ the quantities that should be modified. Equation 21 for combined torsion and bending now becomes:

$$p_{1v} - \lambda_\theta p_{3v} = S_{e\theta} \qquad (24)$$

where:

$$\lambda_\theta = \frac{S_{e\theta}}{\tau_e} - 1 \qquad (25)$$

The formula for λ_θ has been modified to take into account some change in the value of *tensile* strength in directions oblique to the axis of the specimens (assuming the axis is in the direction of rolling). However, the *shear* endurance limit is not changed in the formula for λ_θ for the following reason: The values of τ_e used in the formula for λ_θ are from tests of pure torsion, in which the intensity of actual shear along longitudinal planes is equal to that along transverse planes. τ_e, then, should be the same for "transverse" specimens as for "longitudinal" specimens, that is, $\tau_e(\theta = 0 \text{ deg}) = \tau_e(\theta = 90 \text{ deg})$. For intermediate values of θ the value of τ_e *may* be slightly higher, but no experimental data were found bearing on the problem (although there is some material in the literature (13, 14) from which some idea can be obtained of the order of magnitude of *tension* anisotropy). Probably if λ_θ is modified for $s_{e\theta}$, it ought also to be modified for anisotropy in the shear endurance limit. At present writing the only way to do this is the cut-and-try method. In fact, trial computations were made on the 29 tests reported by Gough (12) for combined stresses on smooth specimens, using various values of $S_{e\theta}$ *and* of $\tau_{e\theta}$. Any change in the value of $\tau_{e\theta}$ for $\theta > 0$ deg produced an appreciable increase in the scatter (σ_d) of the values of $(p_{1v} - \lambda_\theta p_{3v})/s_{e\theta}$. What this indicates is not clear, unless possibly that there is little or no shear anisotropy in Gough's steel, whereas the best results (low σ_d) were obtained for a ratio of $S_e(\theta = 90°)/S_e(\theta = 0°) = 0.85$. Equations used for evaluating the scatter are listed in Table II.

TABLE II.—EQUATIONS USED IN COMPUTATIONS FOR TABLE I.

Use	Equation	Equation No.
The parameter λ_θ	$\lambda_\theta = \frac{s_{e\theta}}{\tau_e} - 1$	(26)
The proposed criterion	$\frac{p_{1v} - \lambda_\theta p_{3v}}{s_{e\theta}} = R$	(27)
Distortion energy theory	$\frac{\sqrt{p_{1v}^2 - p_{1v}p_{3v} + p_{3v}^2}}{s_{e\theta}} = R$	(28)
Maximum Shear Theory	$\frac{p_{1v} - p_{3v}}{s_{e\theta}} = R$	(29)
Maximum Shear with Findley's correction for anisotropy	$\frac{\sqrt{\left(\frac{\sigma_v}{2}\right)^2 + \left(\frac{s_e}{2\tau_e}\right)^2 \tau_v^2}}{s_{e\theta}} = R$	(30)
For vibratory stresses only. Standard deviation of R from R_m, in per cent	$\left(R_m = \frac{\Sigma R}{n}\right)$ $\sigma_d = 100\sqrt{\frac{\Sigma(R - R_m)^2}{n}}$	(31)
Steady Stress Factor	$R_0 = a + mp_{1m}$	(32)
To compute a and m for Eq 32	$na + (\Sigma p_{1m})m = \Sigma R$ $(\Sigma p_{1m})a + (\Sigma p_{1m}^2)m = \Sigma(Rp_{1m})$	(33)
For steady plus vibratory stresses. Standard deviation of R from the line $R_0 = a + mp_{1m}$, in per cent	$\sigma_d = 100\sqrt{\frac{\Sigma(R - R_0)^2}{n}}$	(34)

COMPARISON OF THE CRITERION WITH EXPERIMENTAL FATIGUE DATA

In order to test a proposed general criterion for predicting failure of metals in fatigue, it is necessary to have available tests of fatigue strength under widely varied conditions. There are many sets of test data for simple bending or for simple torsion under reversed stress. There are a few sources of combined-stress test data available for studying a proposed fatigue criterion. By separating the steady stress components from the total varying stresses (and handling them empirically, as already indicated), the criterion could be tested against points anywhere in the tension-compression quadrant, which is the only possible quadrant in which fully reversed fatigue stresses can occur. The report of Gough, Pollard, and Glenshaw (**12**), issued in 1951, provided considerable material of the kind needed and was made the basis of the first studies that led to the final form of the proposed criterion. The material in the Gough report was not sufficiently varied to completely try out the criterion, and it covered only twelve steels and two cast irons. The Findley report (11), although not so varied in combinations of stresses, provided much material on an aluminum alloy. Other sources provided, in small amounts, tests on push-pull or on pulsating loads. All of the studies are summarized in Table I.

Spot checks were made of the distortion energy theory, the conventional maximum shear theory, and the maximum shear theory "corrected for anisotropy" as proposed by Findley (11). (See Table II, Eqs 28, 29, 30.)

It was found that in comparing standard deviations of all tests checked by the distortion energy law the average standard deviation given by Eq 21 was 40 per cent as great. Similarly, for checks against the maximum shear law, Eq 21 averaged 27 per cent as great; and for the modified (Findley) maximum shear law, Eq 21 averaged 65 per cent as great.

Inasmuch as it is known that in fatigue failures the steady stress components of the total stresses produce less effect, pound for pound, than the vibratory stress components, it was decided to separate the two components and establish a criterion for vibratory stresses alone, and then determine the effect of steady stresses when present in reducing the fatigue life. The criterion was applied to vibratory (reversed) stresses, with superimposed steady stresses ranging from 0 to the yield strength of the materials studied, for both smooth and notched specimens, and to pulsating stresses on steel and on aluminum alloys. The *steady* stress reduction factor $(a + mp_{1m})$ was adopted as the result of statistical analyses of the fit of values of $R = (p_{1v} - \lambda_\theta p_{3v})/s_{e\theta}$ plotted against various functions of steady principal stresses. A fair fit was found with $a + m(p_{1m} - \lambda_\theta p_{3m})$. A fair fit was also found when the component of p_{1m} in the direction of p_{1v} was tried in place of $(p_{1m} - \lambda_\theta p_{3m})$. However, the best fit was found when the values of R were compared with the above mentioned quantity $(a + mp_{1m})$. *This is a purely empirical relationship.* The equations used in the comparisons of the criterion with experimental fatigue data and with other criteria are shown in Table II.

The largest value of scatter (σ_d) found is 5.6 per cent (Table I, item 29) for the proposed criterion. The *average* and *maximum* scatter, as shown in Table I, are as follows:

	Criterion			
	Proposed	Distortion Energy	Maximum Shear	Maximum Shear Modified
SMOOTH SPECIMENS				
Number of items, Table I	22	18	15	8
Average standard deviation, per cent	3.85	6.6	12.9	5.55
Maximum standard deviation, per cent	5.5	19.8	28.0	17.0
NOTCHED SPECIMENS				
Number of items, Table I	10	7	...	4
Average standard deviation, per cent	3.5	13.8	...	5.85
Maximum standard deviation, per cent	5.6	26.0	...	7.3

CONCLUSION

The proposed fatigue criterion was tested against bending, torsion, bending and torsion, and tension combined with compression. It was tested against smooth specimens and notched specimens, and against various steels, cast irons, and aluminums. In all cases the "fit" was within the range of experimental scatter, at least for such states of stress as are covered by the tests considered.

REFERENCES

(1) Joseph Marin, "Mechanical Properties of Materials and Design," McGraw-Hill Book Co., Inc., New York, N. Y. (1942).

(2) A. Nadai, "Plasticity, A Mechanics of the Plastic State of Matter," McGraw-Hill Book Co., Inc., New York, N. Y. (1931).

(3) James J. Guest, "The Problem of Combined Stress," *Engineering*, January 8–April 16, 1943, pp. 21–23, 101–102, 281–282, 303–304.

(4) Charles S. Barrett, "Structure of Metals," McGraw-Hill Book Co., Inc., New York, N. Y. (1943).

(5) Frederick Seitz, "The Physics of Metals," McGraw-Hill Book Co., Inc., New York, N. Y. (1943).

(6) John M. Hedgepeth, S. B. Batdorf, and J. Lyell Sanders, Jr., "On the Angular Distribution of Slip Lines in Polycrystalline Aluminum Alloy," *Technical Note No. 2577*, Nat. Advisory Comm. Aeronautics (1951).

(7) S. B. Batdorf, "The Interpretation of Biaxial Tension Experiments Involving Constant Stress Ratios," *Technical Note No. 2029*, Nat. Advisory Comm. Aeronautics (1950).

(8) S. B. Batdorf and Bernard Budiansky, "A Mathematical Theory of Plasticity Based on the Concept of Slip," *Technical Note No. 1871*, Nat. Advisory Comm. Aeronautics (1949).

(9) J. O. Smith, "The Effect of the Range of Stress on the Fatigue Strength of Metals," *University of Illinois Bulletin*, Vol. XXXIX, No. 26, Engineering Experiment Station Bulletin Series No. 334, February 17, 1942.

(10) P. W. Bridgman, "The Effect of Pressure on the Tensile Properties of Several Metals and Other Materials," *Journal of Applied Physics*, Vol. 24, No. 5, May, 1953, pp. 560–570.

(11) William N. Findley, "Combined-Stress Fatigue Strength of 76S-T61 Aluminum Alloy with Superimposed Mean Stresses and Corrections for Yielding," *Technical Note No. 2924*, Nat. Advisory Comm. Aeronautics (1953).

(12) H. J. Gough, H. V. Pollard, and W. J. Clenshaw, "Some Experiments on the Resistance of Metals to Fatigue Under Combined Stresses," *Reports and Memoranda, No. 2522*, Aeronautical Research Council (1951).

(13) J. Majors, Jr., B. D. Mills, Jr., and C. W. MacGregor, "Fatigue Under Combined Pulsating Stresses," *Journal of Applied Mechanics*, Vol. 16, No. 3, September, 1949, pp. 269–276.

(14) J. T. Ransom and R. F. Mehl, "The Statistical Nature of the Fatigue Properties of SAE 4340 Steel Forgings," Symposium on Fatigue with Emphasis on Statistical Approach—II, Am. Soc. Testing Mats., p. 3 (1953). (Issued as separate publication *ASTM STP No. 137*.)

(15) J. A. Sauer and D. C. Lemmon, "Effect of Steady Stress on Fatigue Behavior of Aluminum," *Transactions*, Am. Soc. Metals, Vol. 42, pp. 559–576 (1950).

(16) H. L. Cox and J. E. Field, "The Initiation and Propagation of Fatigue Cracks in Mild Steel Pieces of Square Section," *Aeronautical Quarterly*, Vol. IV, Part I, August, 1952, pp. 1–18.

APPENDIX

LIST OF SYMBOLS

Symbol	Description
a	A constant
b	A constant
E	Modulus of elasticity
m	A constant
n	The number of test values
p_a	Average of the maximum and minimum principal stresses
p_{1m}	Principal maximum steady (mean) stress
p_{1v}	Principal maximum vibratory stress
p_{2v}	Principal minimum vibratory stress (Eqs 1 to 20)
p_{3v}	Principal minimum vibratory stress (except Eqs 1 to 20)
R	A ratio
s_e	Endurance limit in plain bending
$s_{e\theta}$	Endurance limit in plain bending in direction of p_{1v}
θ, β, γ	Directional angles of the normal to any plane
θ	Angle between direction of rolling or forging and direction of p_{1v}
λ	A coefficient
λ_θ	A coefficient = $(s_{e\theta}/\tau_e) - 1$
σ_d	Standard deviation, in per cent
σ_n	Maximum stress normal to the critical shear plane
σ_v	Vibratory nominal tensile stress in axial direction at endurance or fatigue limit
τ	Maximum shear stress
τ_c	Critical shear stress
τ_e	Shear endurance or fatigue limit, in pure torsion
τ_{e0}	Critical shear stress in fatigue when the normal stress is zero and when no other plane is involved
τ_θ	Shear stress on a plane whose normal subtends an angle θ with the major direction
τ_v	Vibratory nominal transverse shear at endurance or fatigue limit
ϕ	Angle with σ_n-axis made by graph of τ_c *versus* σ_n.

EXPERIMENTS IN FATIGUE UNDER RANGES OF STRESS IN TORSION AND AXIAL LOAD FROM TENSION TO EXTREME COMPRESSION*

By William N. Findley[1]

Synopsis

Axial-load fatigue tests were performed on SAE 4340 steel at mean stresses from 40,000 psi in tension to 135,000 psi in compression (a stress equal to the tensile strength). In the extreme compression tests the entire stress cycle was a compression stress of 20,000 psi or greater. This was done to determine whether fatigue cracks could form and propagate in a cycle containing no tensile stresses.

A technique for doubling the yield point in compression was also demonstrated and used in the fatigue tests.

An experiment was also performed on 75S-T aluminum alloy to determine whether the large effect of mean stress on the fatigue strength in tension and the small effect in torsion were due to the change in structure of the material resulting from inelastic action or to other causes.

A test was made of the same alloy in torsion fatigue to evaluate the influence of the complementary normal stress.

The effect of range of stress in fatigue has been studied by many investigators, usually for ranges of stress in which the mean stress of the cycle was a tensile stress. A summary of the work in this area up to 1942 is contained in a paper by Smith (**1**)[2] and a more recent summary is available in reference (**2**). The results of all of these tests indicate that the fatigue strength, defined in terms of the alternating stress amplitude, decreases as the mean stress (or maximum stress) of the cycle increases to higher tensions. The rate of decrease in fatigue strength with tensile mean stress depends apparently on the material and varies from slight to large with different materials.

A smaller number of tests have been made in which the mean stress of the cycle was a compression stress. These results were also reviewed by Smith (**1**) and recently by Newmark, Mosborg, Munse, and Elling (**3**). As far as is known no previous tests have been performed in which the entire stress cycle, including the smallest stress of the cycle of stress, was a compression stress. Available fatigue tests with mean stresses in compression indicate a slight to large increase in fatigue strength with increasing values of compressive mean stress.

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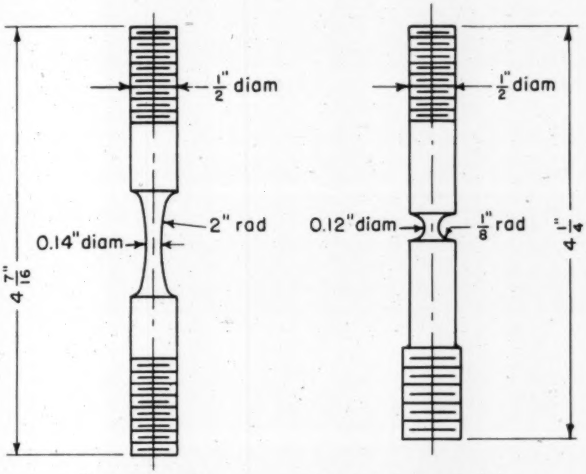
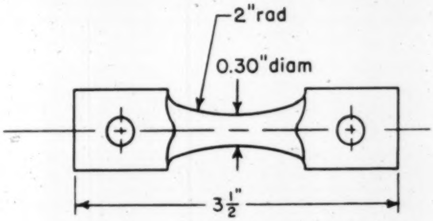
[2] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 846.

Fatigue tests under axial loads in which any portion of the stress cycle is in compression have always been difficult to perform owing to the problem of insuring a uniform stress distribution and freedom from buckling. Special testing apparatus was designed especially to meet this problem and was described in 1947 (4). The present series of tests was begun in 1949 using this apparatus. Another recent attack on this problem is described in reference (3).

The phenomenon of an increase in fatigue strength resulting from a compressive mean stress is of considerable importance since it has been observed that the fatigue resistance of machine parts can be increased considerably by producing surface residual stresses in compression. The residual stresses should have the same action in fatigue as the mean stresses in an imposed stress cycle if the state of stress is the same in both cases. Hence, a study of the effect of mean stresses should contribute to our knowledge of the effect of residual stresses.



(*a*) Axial tension. (*b*) Axial compression.



(*c*) Torsion

FIG. 1.—Fatigue Specimens.

In a previous paper (5) it has been suggested that initiation of fatigue may be produced primarily by the alternating shear stress and that the effect of mean stresses may be that of increasing the maximum stress of the cycle and thus altering the structure of the material by yielding and other inelastic action and by elastic distortion. It has also been suggested in closing discussion of reference (2) and reference (6) that the fatigue resistance may also be influenced by the magnitude and sign of normal stresses on the plane of the maximum shear stress and on the plane perpendicular to the maximum shear planes. The effect of normal stresses like the effect of structural change may be different for different materials. That is, normal stresses on the planes of maximum shear stress may tend to inhibit slip, if compression, or make slip easier, if tension; and the effectiveness of these normal stresses may depend on the nature of the atoms involved in the potential slip planes, presence of foreign atoms, and type of lattice.

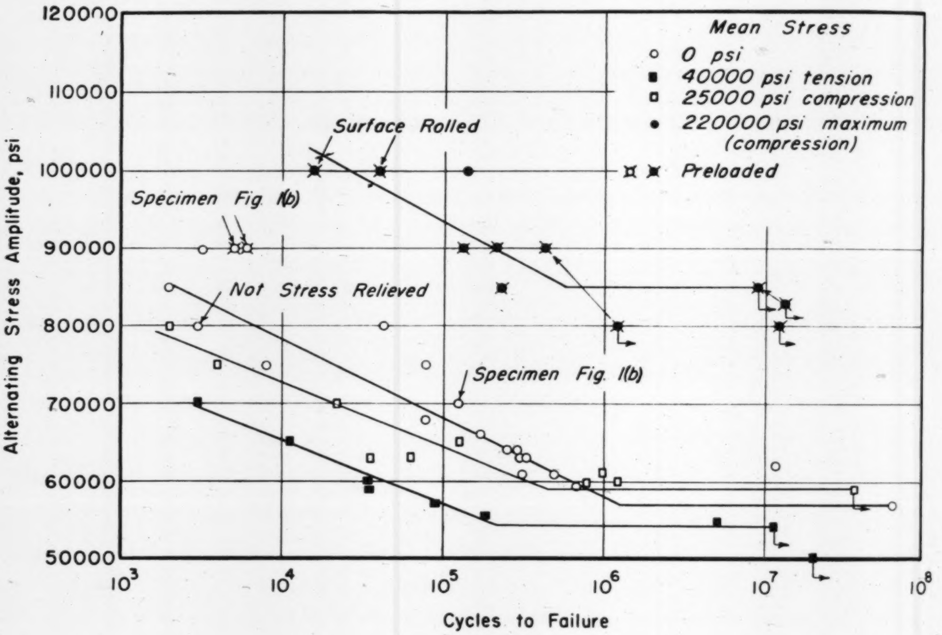


FIG. 2.—Fatigue Tests of SAE 4340 Steel in Axial Load.

In order to evaluate some of the above and other possibilities described later, the tests and experiments described below were performed.

MATERIALS, SPECIMENS, APPARATUS, AND TECHNIQUE

An SAE 4340 steel heat treated to a Rockwell hardness of C 25 and a 75S-T6 aluminum alloy were tested in this project. The steel is the same as employed and fully described in previous work (2,7). The present specimens were drawn at a temperature of 1250 F which produced the above hardness. The 75S-T6 aluminum alloy is from the same stock described in references (8,9,10).

Specimens were machined to the dimensions shown in Fig. 1 and polished in accordance with the procedure outlined in reference (2), considering the reduced section of the specimen in Fig. 1(*b*) to be a notch. Actually the stress concentration factor for this specimen was small, 1.13. A portion of the specimens of Fig. 1(*a*) prepared of SAE 4340 steel was subjected to a final drawing operation at a temperature of 1260 F in a vacuum retort in order to relieve residual stresses induced by machining and polishing.

The apparatus employed has been described previously both for the axial-load fatigue machine (4) and the Krouse fatigue machine modified for bending and torsion fatigue tests (11).

The techniques employed in conducting these fatigue tests were the same as previously described (2,4,5,11,12) except as discussed in the following sections.

EFFECT OF MEAN STRESS IN AXIAL-LOAD FATIGUE TESTS

The effect of mean stress on the fatigue strength of SAE 4340 steel from the same stock has been studied at two values of Rockwell hardness, C 25 (7) and C 38 (2). Both tests showed only a small decrease in fatigue strength with increase in mean stress in both bending and torsion tests. In order to minimize the possible effect of stress gradient, present in both bending and torsion tests, axial-load fatigue tests were performed on the same material with a Rockwell hardness of C 25, using the specimen shown in Fig. 1(*a*). Tests at zero mean stress and at stresses near the endurance limit for other values of mean stress were made on specimens which were given a stress-relief draw in a vacuum after machining. The resulting *S-N* diagram for zero mean stress is shown in Fig. 2. The scatter in results at high stresses cannot be explained except in terms of differences in skill of two operators.

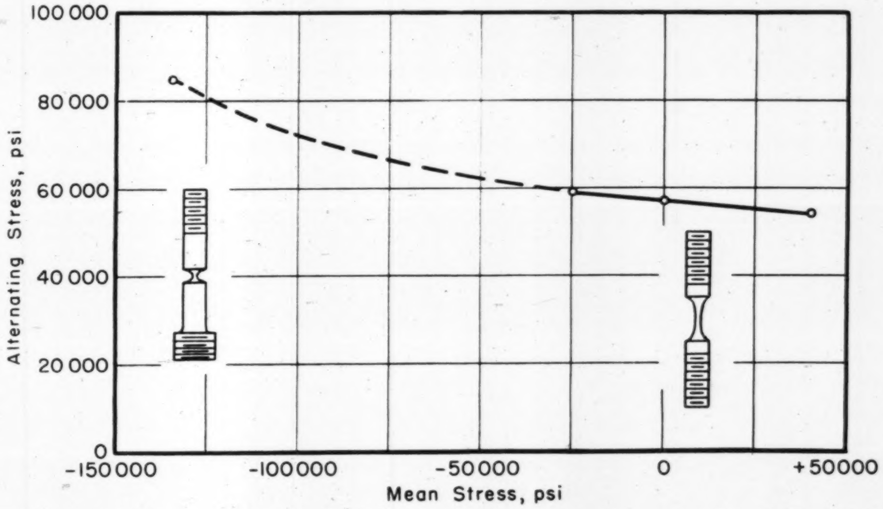


FIG. 3.—Effect of Mean stress on Endurance Limit of SAE 4340 Steel (Rockwell Hardness, C 25).

Fatigue tests were also performed (*a*) at as high a tension mean stress, 40,000 psi, as could be applied without continuous yielding at constant load, and (*b*) at as high a compression mean stress, 25,000 psi, as the specimen shown in Fig. 1(*a*) could withstand without buckling or unsymmetrical yielding. These *S-N* diagrams are also shown in Fig. 2. The endurance limits from these tests are shown as a function of mean stress in Fig. 3. The largest obtainable mean stress in tension was only one third of the largest nominal mean stress employed in the bending fatigue tests (7) and the endurance limit was about 15 per cent lower.

It was observed that the endurance limit decreased with tensile mean stress in the axial-load tests more than in the bending tests.

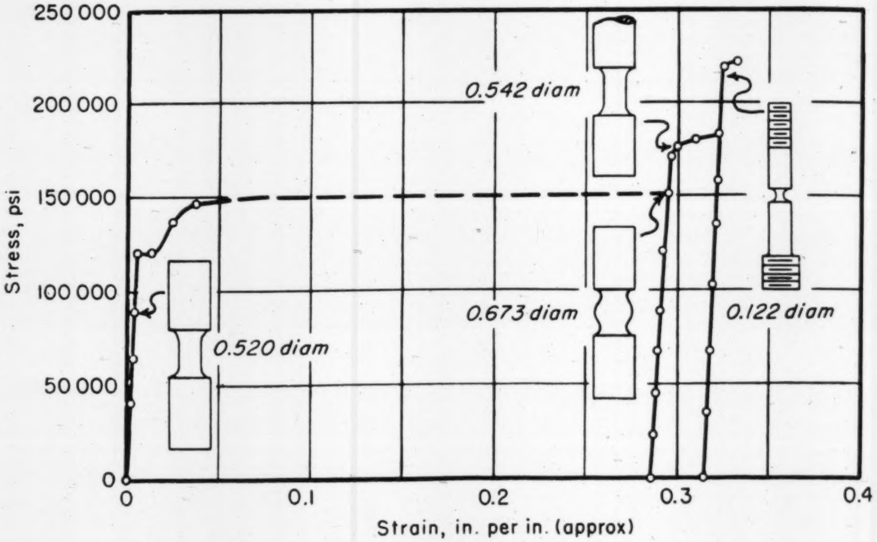


FIG. 4.—Stress-Strain Tests of SAE 4340 Steel in Compression.

COMPLEMENTARY NORMAL STRESS

It was considered (2) that the inception of fatigue resulted from alternating shearing stress and that the resistance to fatigue was influenced by the magnitude and sign of the complementary normal stress. The resistance to fatigue would be increased by compressive values and decreased by tensile values of the complementary normal stress. Since the maximum stress of a cycle can be increased without changing the alternating stress, the complementary normal stress in bending or axial-load tests is increased by increasing the maximum stress (or mean stress) without changing the alternating shearing stress. Thus, it might be that the decrease in fatigue strength noted in the SAE 4340 steel resulting from tensile mean stress and the increase resulting from the compression mean stress are caused by the complementary normal stress. This assumes that the material is not altered by the maximum stresses applied.

The fact that in torsion tests the complementary normal stress is zero for all values of mean stress suggests that the mean stress in torsion should have no effect if the material is not altered by the maximum stresses. For some materials, the fatigue resistance in torsion is affected considerably by mean stress, but the SAE 4340 steel is affected only slightly. This may mean that the structure of this material is not altered much by moderate straining.

FATIGUE TESTS IN EXTREME COMPRESSION

The indicated influence of the complementary normal stress on the resistance to fatigue suggests that there may be a value of compressive normal stress which would prevent the inception or propagation of fatigue cracks if the normal stress is high enough. In order to test this possibility, higher mean stresses in compression were attempted by reducing the radius of the test section to successively smaller values. In this way, nominal compressive stresses as high as 200,000 psi were sustained, but the large yielding which resulted deformed the test section unsymmetrically and caused bending stresses and an enlarged cross-sectional area. Fatigue cracks transverse to the cross-section were observed.

In order to determine the number of cycles at which fatigue cracks commenced, the specimen was inspected with a magnifying glass every 10 min at first, then at longer periods as the test progressed.

Increase in Yield Point by Preloading:

The problem of distortion of the test section by unsymmetrical yielding was solved by preyielding the specimen as illustrated in Fig. 4. A specimen of the shape shown at the left in Fig. 4 was loaded in a compression tool by a static testing machine until the specimen bulged as shown. Loading was continued until the load increased very slowly to a nominal stress of 250,000 psi. At this point the stress based on the actual diameter at the bulge was about 150,000 psi, which was 30,000 psi higher than the original yield point. The specimen was then unloaded and reloaded for five cycles.

The bulge was then removed by machining the specimen to the shape shown in the top drawing of Fig. 4. The specimens was again compressed until well beyond the new yield point, then unloaded, and reloaded again for five cycles. During this compression, the specimen did not yield until 170,000 psi. Following this loading, the specimen was machined to the shape used for fatigue tests as shown in Fig. 1(*b*).

The specimen was mounted in the axial-load fatigue machine using a different type lower grip which introduced less distortion during clamping than the previous grips. This was necessary because the shorter test section did not permit as much distortion during gripping as the specimen of Fig. 1(*a*). The elastic distortion produced was removed by the adjustments previously described (**4**) and the specimen was loaded statically, recording load and deformation as shown in Fig. 4.

This time the specimen did not yield until a stress of 220,000 psi was reached. This means that the yield point of this high-strength steel had been increased by cold work from 120,000 to 220,000 psi.

Fatigue Tests in Compression:

Specimens prepared in this way were tested in fatigue with the results shown in Fig. 2 by the plotted points with a superimposed x. Some relaxation of the load occurred during the first part of the test and was corrected by replacing the distortion detector (**4**) and adjusting the load periodically. Two of the specimens which did not fail were tested again at a higher stress as indicated in Fig. 2 by the diagonal arrows. One of the points at 100,000 psi alternating stress represents one of the earlier tests without preloading. The stress was actually lower than shown because the diameter was enlarged by yielding.

Tests shown by black circles had a maximum compressive stress in the cycle of 220,000 psi and alternating stresses as shown. Thus, the stress cycle always had a nominal compressive stress of 20,000 psi or greater. Hence, no tensile stress in the axial direction could be present at any part of the stress cycle unless residual stresses or peak stresses from some other source exceeded 20,000 psi.

Fatigue cracks were observed at the number of cycles indicated. They were transverse to the specimen at the minimum section. It was observed that these cracks started on the surface, progressed only to a certain depth, and then appeared to stop. This depth was observed to be from 0.01 to 0.045 in. For specimens tested at 90,000 psi alternating stress and 130,000 psi mean stress, cracks were observed at about 2×10^5 cycles, and crack depth varied from 0.01 to 0.025 in. In a specimen tested at the same mean stress and an alternating stress of 85,000 psi, cracks were observed at 2.1×10^5 cycles, and after 1.9×10^7 cycles the crack depth was 0.015 in.

The endurance limit at this high compressive mean stress was substantially increased as shown in Fig. 3. To test whether the yielding itself had substantially increased the fatigue strength, two specimens given the same preloading described above were tested at 90,000 psi alternating stress and zero mean stress. The results shown in Fig. 2 indicate that there was no marked increase in fatigue strength. The Bauschinger effect, however, probably influenced these results.

Thus, it may be reasonable to conclude that the presence of a high compressive value of complementary normal stress increases the fatigue resistance and that a compressive mean stress at least retards the propagation of fatigue cracks.

To test whether the shape of specimen shown in Fig. 1(*b*) had a substantial fatigue strength reduction factor, a specimen of this shape was tested without preloading at zero mean stress and 70,000 psi alternating. The result shown in Fig. 2 is in agreement with data from the specimens of Fig. 1(*a*).

Effect of Surface:

Since the fatigue cracks started on the surface, it would be desirable to know what caused this surface weakness. One possibility is the slight stress concentration in these specimens. This effect would presumably cause a larger amplitude of stress on the surface and greater maximum compressive stresses. These maximum stresses might be blunted by yielding so that on unloading elastically the minimum stress of the cycle would be a smaller compression on the surface than the center and possibly, but not likely, even slightly tensile.

Both of these factors would tend to produce surface weakness. In addition it was suggested in an unpublished memorandum that surfaces may be weaker than center material because the ends of some potential slip planes which terminate at a surface are less restrained than those in the interior, since slip of the latter is inhibited by neighboring grains on all sides. This explanation may also be responsible for the even greater fatigue weakness of corners, since in this case two sides of some potential slip planes are exposed and less restrained.

Thus, it was considered that the initiation of fatigue cracks under the compression range of stress might consist of repeated slip in surface grains where the resistance to slip was the least. This local slip might alter the geometry so as to relieve locally the compressive normal stress on these planes and permit cracks to appear on slip planes. An explanation for the propagation of cracks on planes having only compressive stress is not available except through the postulation of microresidual stresses of large magnitude and tensile sign.

It seemed desirable, in view of the above, to try to determine whether fatigue cracks could start in the interior under high compressive mean stresses if the surface cracks were suppressed. It seemed unlikely that cold working the surface would be a successful method after the precompression the specimens received, but no other method of strengthening the surface was available. To cold roll the surface a tool was developed to roll the test section of the specimen shown in Fig. 1(*b*) simultaneously on opposite ends of a diameter. This means was employed to prevent distortion of the specimen.

Two specimens preloaded as described above except for the last loading were rolled on the surface at loads calculated to produce yielding to a depth of about 0.007 and 0.008 in., respectively, and then tested in fatigue at stresses of 220,000 psi maximum stress and 100,000 psi alternating stress each, as shown in Fig. 2. These specimens appear to have been no stronger and possibly weaker than the specimens tested without surface rolling, and surface cracks were not suppressed. Strangely, the specimen with the larger cycles-to-failure had a low hardness reading.

INFLUENCE OF MEAN STRESS AND YIELDING

In order to evaluate how much of the change in fatigue strength with mean stress was due to the mean stress alone and how much was due to the yielding or other structural change resulting from the maximum stress, the following tests were performed on the SAE 4340 steel. Four specimens of the type of Fig. 1(*a*) were first given an initial tension stress of 100,000 psi, then stretched to twice the elongation in 2 in. at 100,000 psi.

Two of the specimens were then tested at a mean stress which caused the maximum strain to be 2 per cent less than the maximum prestrain and an alternating stress of 65,000 psi. The other two specimens were tested at zero mean stress and an alternating stress of 65,000 psi. Specimens from the first group failed at 6000 and 10,000 cycles; those from the second group at 31,000 and 25,000 cycles—not much difference. The sample size, however, was small.

The results indicate a small decrease (about 8 per cent) in fatigue resistance with increase in mean stress and a larger decrease (about 15 per cent) in fatigue strength at zero mean stress resulting from the prestraining.

This study was extended to 75S-T6 aluminum in order to provide data from a material in which the influence of tension mean stress was pronounced (**13**). In this experiment fatigue tests were performed on the axial-load fatigue machine. The specimens tested were given one of the following static loadings prior to fatigue testing:

Type A preload.—None.

Type B preload.—Stretched into the yield range until a stress of 78,200 psi was reached, then unloaded as far as the minimum stress to be used in the particular fatigue test.

Type C preload.—Stretched into the yield range until a stress of 78,200 psi was reached, then unloaded to the compressive stress encountered in a test at zero mean stress, then reloaded to 78,200 psi, and cycled twice between these two loads.

The following fatigue tests were performed: (*a*) tests at zero mean stress of specimens having no prior load history, (*b*) tests at a high mean stress in tension of 60,000 psi and type B preload, (*c*) tests at a high mean stress of 60,000 psi and type C preload, and (*d*) tests at a mean stress of zero and type C preload. The tests were planned so as to produce results of at least three tests at the same alternating stress the average-log N of which was about the same for tests (*a*), (*c*), and (*d*). Thus, the fatigue strength for the three series of tests could be compared at the same number of cycles. The results are shown in Fig. 5.

It was observed that the fatigue strength at 3×10^6 cycles was reduced

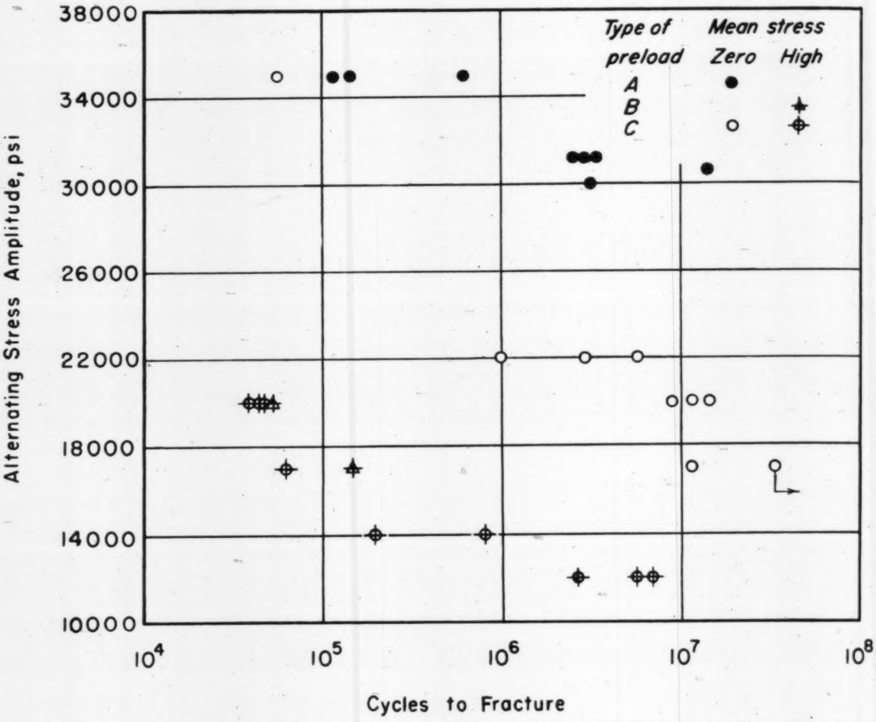


FIG. 5.—Fatigue Tests of 75S-T6 Aluminum in Axial Load with Tension Mean Stress.

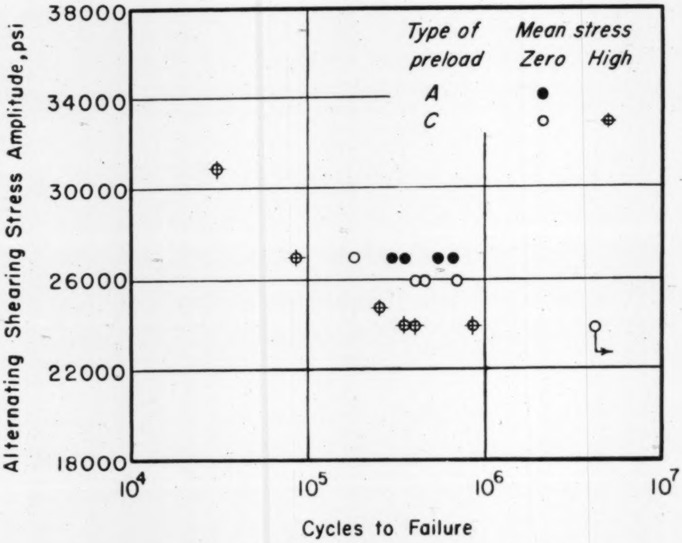


FIG. 6.—Fatigue Tests of 75S-T6 Aluminum in Torsion.

by 30 per cent by the preloading alone and 60 per cent by the preloading and mean stress combined. Type B preloading appeared to give much the same results at high mean stress as type C preloading.

These results indicate that both structural change resulting from the maximum stress and the mean stress itself are influential in reducing the fatigue strength under axial loads when the mean stress is increased.

INFLUENCE OF COMPLEMENTARY NORMAL STRESS

As indicated above, the complementary normal stress is zero for all values of mean stress in torsion. If the complementary normal stress was the factor which caused the variation in fatigue strength with mean stress in axial load tests, then torsion tests should be useful to evaluate this possibility.

A series of torsion tests was performed on 75S-T6 aluminum following the same plan as outlined above for the axial load tests of this alloy except that type B preload and fatigue tests (*b*) were omitted. The value of the high mean stress employed in the torsion fatigue tests was 18,000 psi.

The results of the torsion fatigue tests are shown in Fig. 6. It was observed that the fatigue strength in torsion at 5×10^5 cycles was reduced 4 per cent by the preloading alone and 11 per cent by the preloading and mean stress combined.

Comparing these results with those from the axial load tests, it is evident that the complementary normal stress has a considerable influence on the reduction of fatigue strength by structural change under the maximum stress of the cycle and also on the reduction of fatigue strength by the mean stress of the cycle.

From the above it may be postulated that the observed improvement of the fatigue strength in torsion resulting from shot peening probably results from the following causes: (*a*) Introduction of bi-axial residual compressive stresses which result in compressive normal stresses being present on all planes of principal shear stress in the surface of the torsion bar. Thus the stress state is changed from that for simple torsion to one more nearly like that for axial load (or bending). The normal stresses acting on the principal shear planes tend to raise the fatigue strength of the surface layers. (*b*) Material strengthening resulting from plastically deforming the material in compression under the action of shot peening. While there is not much evidence on this point, it consists of the facts that: tensile plastic deformation reduces the fatigue strength as shown in Fig. 5; and plastic deformation in compression increases the fatigue strength, if it affects it at all, as shown by the two tests reported in Fig. 2.

CONCLUSIONS

1. At moderate values of mean stress (both tension and compression) the fatigue strength of SAE 4340 steel decreased slightly as the mean stress was changed from compression to tension.

2. At high compressive mean stress the fatigue strength increased substantially, fatigue cracks initiated at the surface progressed to a certain depth and stopped even though the stress cycle never had a compressive stress less than 20,000 psi.

3. The extreme compression specimens were produced by preyielding the specimen, machining off the bulge, and reloading. By this process, the yield point was nearly doubled.

4. Surface rolling of preyielded specimens did not appear to have influenced the fatigue strength in compression.

5. Both structural change resulting from the maximum stress of a cycle and the mean stress itself were found to

influence the fatigue strength of SAE 4340 steel and 75S-T6 aluminum.

6. The complementary normal stress was also found to be an important factor in fatigue of both materials.

7. Other observations and conclusions are discussed in the text.

Acknowledgment:

This investigation was executed as part of the work of the Engineering Experiment Station in the Department of Theoretical and Applied Mechanics of the University of Illinois with the financial assistance of the Office of Ordnance Research, U. S. Army.

The author is especially indebted to W. A. Hagemeyer, W. F. Wendt and M. E. Henley for performance of tests and preparation of drawings for this paper.

REFERENCES

(1) J. O. Smith, "The Effect of Range of Stress on the Fatigue Strength of Metals," *Bulletin No. 334*, Engineering Experiment Station, University of Illinois, Urbana, Ill. (1942).

(2) W. N. Findley, F. C. Mergen, and A. H. Rosenberg, "The Effect of Range of Stress on Fatigue Strength of Notched and Unnotched SAE 4340 Steel in Bending and Torsion," *Proceedings*, Am. Soc. Testing Mats., Vol. 53, p. 768 (1953).

(3) N. M. Newmark, R. J. Mosborg, W. H. Munse, and R. E. Elling, "Fatigue Tests in Axial Compression," *Proceedings*, Am. Soc. Testing Mats., Vol. 51, p. 792 (1951),

(4) W. N. Findley, "New Apparatus for Axial-Load Fatigue Testing," ASTM BULLETIN, No. 147, August, 1947, p. 54.

(5) W. N. Findley, "Combined Stress Fatigue Strength of 76S-T61 Aluminum Alloy with Superimposed Mean Stresses and Corrections for Yielding," *Technical Note 2924*, Nat. Advisory Committee for Aeronautics, May, 1953.

(6) W. N. Findley and P. N. Mathur, "Anisotropy of Fatigue Strength in Bending and in Torsion of a Steel and Two Aluminum Alloys," *Technical Report No. 3*, Office Ordnance Research, Contract No. DA-11-022-ORD-995, May, 1954.

(7) B. C. Hanley, "The Effect of Range of Stress and State of Stress on the Fatigue Strength of SAE 4340 Steel," *Technical Report No. 22*, Office of Naval Research, Contract N6-ori-71, T.O. IV, Feb., 1951.

(8) G. M. Sinclair, "An Investigation of the Coaxing Effect in Fatigue of Metals," *Proceedings*, Am. Soc. Testing Mats., Vol. 52, p. 743 (1952).

(9) T. J. Dolan and H. F. Brown, "Effect of Prior Repeated Stressing on the Fatigue Life of 75S-T Aluminum," *Proceedings*, Am. Soc. Testing Mats., Vol. 52, p. 733 (1952).

(10) H. T. Corten, G. M. Sinclair, and T. J. Dolan, "An Experimental Study of the Influence of Fluctuating Stress Amplitude on Fatigue Life of 75S-T6 Aluminum," see p. 737 this publication.

(11) W. N. Findley and W. I. Mitchell, "Two Machines for Combined Bending and Torsion Fatigue," *Proceedings*, Soc. Experimental Stress Analysis, Vol. XI, No. 1, pp. 203–212 (1953).

(12) Manual on Fatigue Testing, Am. Soc. Testing Mats. (1949). (Issued as separate publication *ASTM STP No. 91*.)

(13) B. J. Lazan and A. A. Blatherwick, "Fatigue Properties of Aluminum Alloys at Various Direct Stress Ratios," *Technical Report 52-307*, Part I, Wright Air Development Center, Dec., 1952.

DISCUSSION

Mr. J. T. Ransom.[1]—There has been a great deal of publicity about the benefits in resistance to fatigue to be obtained by introducing compressive residual stresses into machine parts by means of cold-working the surfaces. I do not think anyone will deny that the process of shot peening or otherwise cold-working the surface does improve performance. However, I do not feel that anyone has yet proven conclusively that residual compressive stresses are the entire reason for that improvement. It is gratifying to find someone carrying out an experimental investigation of this subject.

To me the increase in safe range of alternating stress as the mean stress was made more compressive—which Mr. Findley has found—is not comparable to the degree of improvement obtained in practice by the use of surface-working treatments. Therefore, I believe there is more to this surface-working phenomenon than merely the introduction of residual stresses.

At duPont, D. L. Macleary and the writer have started a program of axial load testing similar to that reported by Mr. Findley, and our results to date parallel his in most ways. Perhaps a preliminary report at this time would be of interest.

We are using SAE 4340, heat-treated to a hardness of Rockwell C 28, as did Mr. Findley. However, our specimens are taken with the specimen axis transverse to the forging direction. Because of the anisotropy existent in forgings, the fatigue limits found on these specimens could be as much as 50 per cent lower than those reported by Mr. Findley for longitudinal specimens. The axial-load tests are carried out on a Sonntag SF-10-U fatigue machine, using gripping fixtures which have been shown by calibration tests to produce less than 2 per cent extraneous bending stresses in the specimen. Three series of tests are in progress. The minimum stress of the cycle is fixed at 0, −50,000, or −100,000 psi, respectively, in each of the three series of tests, and the fatigue limit is measured as the safe range of stress possible with these minima. The case of a minimum stress of zero results in tension stress throughout the cycle; the case of a minimum stress of −50,000 psi was expected to result in a nearly reversed stress test at the fatigue limit, while the case of the minimum stress at −100,000 psi was expected to result in a stress range almost wholly compressive at the fatigue limit.

The results to date are incomplete but do indicate that the safe range of stress may be increased by as much as 50 per cent in going from repeated tension to almost repeated compression. A few preliminary tests showed that in the case of repeated stresses wholly within the compressive range, it was necessary to exceed the nominal tensile yield strength (115,000 psi) of the steel by about 15 per cent before fatigue cracks were initiated. The cracks then formed on 45-deg planes.

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[1] Research Project Engineer, Engineering Research Laboratory, Engineering Department, E. I. du Pont de Nemours and Co., Inc., Wilmington, Del.

As an interesting sidelight, the repeated axial tension tests gave the same fatigue limit (70,000 psi) as was obtained by using repeated bending tests. It is our opinion that repeated axial tension tests usually result in lower fatigue limits than do repeated bending tests because of lack of alignment in the axial fixtures.

I should like to ask Mr. Findley two questions to which I am sure he has already given much thought. First, how does he know that the tests were truly axial and did not have unknown bending stress superimposed? In particular, the specimen which was remachined after several compressive loadings has a very small test section and would appear to be very susceptible to errors in alignment. Second, in the preloaded specimens which were remachined, does he feel that the residual stresses introduced by the nonuniform deformation and the machining operation were insignificant or how might they have influenced the results?

MR. GEORGE GOHN.[2]—Figure 3 shows the effect of variable compressive mean stresses on the fatigue strength. One point way out to the left represents a very high mean compressive strength which the author stated, in explaining Fig. 4, was obtained by compressing a test specimen beyond the point of permanent plastic deformation and then machining off the excess material.

Now the curves shown in Fig. 4 indicate a very marked effect of such plastic deformation on some of the physical properties, notably the yield strength. It is obvious that the fatigue strength was probably affected, too, and it seems to me that it is rather unfair to treat a point obtained from plastically deformed material as part of the same group of specimens as those which had no such plastic deformation. In other words, if the specimens used had all been plastically deformed and then machined before testing, then all of the tests would have been made on the same material and the author would be justified in making a comparison of the various test results.

Most of our own work has been confined to non-ferrous materials, and one of the ways for obtaining better fatigue properties is plastically to deform or cold-work the materials. With such cold-working an improvement of 40 to 50 per cent in fatigue strength is possible. Therefore, it seems to me that in this particular case Mr. Findley may be comparing two materials which are not essentially the same. If so, the comparison is not warranted.

MR. GEORGE SINES.[3]—I compliment Mr. Findley on his clear presentation of the factors at work when static and alternating stresses are superimposed and on the development of the techniques for fatigue testing in the compressive range.

At the University of California at Los Angeles,[4] we also came to some conclusions similar to those presented here, that is, that the fatigue failure is caused by the alternation of shear stress and that static stress influences the permissible alternation by the action of its normal components. The generalization may be refined by using the octahedral shear stress instead of the simple shear stress, because this averages the effects over many slip planes of the polycrystalline material.[5] The applicability may also be extended by replacing the "complementary stress," defined by the author to be the static normal stress on the plane of maximum shear, by the sum of the orthogonal static normal stresses. Tests on the effect of static torsion on alternating bending[6, 7] show no effect of the torsion on the bending fatigue until the yield is exceeded. For this case the complementary stress is not zero and an effect would be predicted. However, let us look at the sum of the orthogonal static normal stresses for this case. Although the sum is independent of the coordinates, we will choose them so that one is the complementary stress, the other is normal to the free surface, and the third orthogonal to the other two. When static torsion is added to alternating bending of a circular shaft, the normal stresses resulting from torsion alone on the planes of maximum shear stress for bending alone are equal in magnitude but opposite in sign, while the third normal stress (normal to the surface) is zero for both bending and torsion. Thus the sum of the three normal stresses added as a result of the static torsion is zero. Hence the sum of the three normal stresses for alternating bending plus static torsion is the same as for alternating bending alone. Thus the observed independence of the static stress is predicted for this case. Further examination would show agreement with the effect of axial compression or tension and the effect of static torsion on alternating torsion.

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[2] Supervisor, Creep and Fatigue Laboratories, Bell Telephone Laboratories, Inc., New York, N. Y.

[3] Assistant Professor, Institute for the Study of Metals, The University of Chicago, Chicago, Ill.

[4] George Sines, "Failure of Materials Under Combined Repeated Stresses with Superimposed Static Stresses," *Report 54-9,* University of California, Nat. Advisory Comm. Aeronautics Contract NAw-6161, Jan., 1954.

[5] G. Sachs, "Zur Ableitung einer Fliessbedingung," *Zeitschrift des Vereines deutscher Ingenieure,* Vol. 72, p. 734 (1928).

Possibly the dependability of existing data does not warrant such refinement; however, I hope speculation may encourage more fatigue testing with the same precision used by Mr. Findley.

MR. W. N. FINDLEY (*author's closure*).—These helpful discussions are appreciated. I am in general agreement with Mr. Ransom's remarks. It is gratifying to note that fatigue cracks developed at 45 deg in Mr. Ransom's tests of SAE 4340 steel under compressive mean stress. I had expected such a mode of fracture but observed instead only transverse cracks. The bending fatigue tests of the SAE 4340 steel which I tested had an endurance limit of 67,000 psi, at Rockwell C 25, which was 14 per cent higher than the axial load tests.

It has been my opinion that lack of alignment in axial load tests would produce lower fatigue limits when the misalignment caused fluctuating bending or twisting, but only a slight effect, depending on the material, when the bending or twisting was steady. I have also felt that a lower fatigue limit should be expected in axial load tests because fatigue cracks developing at the surface involve slipping along a finite plane in certain crystals. Since these planes extend below the surface of the material, the average stress on these planes will be less in bending than in axial load tests for the same surface stress. Thus, I would expect a lower fatigue strength in axial load tests.

In response to Mr. Ransom's questions, I do not of course know that the tests were absolutely axial. Bending and twisting deformations were detected and removed by means of apparatus described in reference (4) of the paper. The absolute precision of this method is not known. I think it is better than could be obtained with strain gages on the small specimens employed. One indication that the stresses were uniform across the section is that the depth of penetration of the cracks in the extreme compression tests was uniform around the periphery. If bending stresses were present, I would expect nonuniform penetration.

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[6] E. C. Lea and H. P. Budgeon, "Combined Torsional and Repeated Bending Stresses," *Engineering*, London, Vol. 122, p. 242 (1926).

[7] Akimasu Ono, "Fatigue of Steel Under Combined Bending and Torsion," ***Memoirs of the College of Engineering***, Kyushu Imperial University, Japan, p. 117 (1929).

The method of preparation of the precompressed specimens was especially selected to minimize macro residual stresses. From the absence of warping during the machining and the large proportion of material removed during machining, I feel that significant macro residual stresses were absent. Micro residual stresses were probably present and significant, however. In other words, there is probably a very rapid change in residual stress across the grains but not across the section.

In criticizing the paper for comparing results of tests of materials having received plastic deformation with those which had not, I believe Mr. Gohn has misunderstood the paper. It was recognized that any mechanical test changes the material during the test. So one of the purposes of the paper was to discover how much of the effect of large static stresses on the fatigue strength was due to stressing and how much to change in the material resulting from yielding.

Mr. Sines' kind remarks are very much appreciated. In his discussion Mr. Sines suggested that the theory be refined by using the octahedral shear stress instead of the principal shear stress. In other papers,[8, 9] I have discussed the applicability of the octahedral shear stress to fatigue. It is my opinion that it is not the most applicable theory since fatigue failure is a very localized phenomenon initiating on specific planes of particular crystals. Thus in a polycrystalline material one would expect the maximum shear stress to be the significant stress, not some lesser or average value, such as the octahedral shear stress. In this respect I consider fatigue to be different from general yielding or creep, in both of which the observed behavior is the average effect of actions on many planes in many crystals.

The suggestion of the sum of the orthogonal static normal stresses as a modifying parameter is interesting. As indicated previously,[10] I consider that the two normal stresses lying in the plane of the principal shear stress and normal to the planes of lesser principal shear stresses probably influence the ability of the material to resist fatigue failure. However, in my opinion the effect of these two normal stresses would be a second or third order effect. I do not see how they could influence fatigue resistance to the same degree as the complementary normal stress—which would be the case if the sum of the orthogonal static normal stresses proposed by Mr. Sines was the significant modifying stress.

The conclusions of Lea and Budgeon[6] and Ono,[7] that static torsion superimposed on alternating bending show no effect of the torsion until the yield is exceeded, are cited by Mr. Sines in support of the proposed theory. In this connection it may be instructive to examine another series of tests of this type by Gough.[11] These tests were conducted on a high nickel-chromium-molybdenum steel heat treated to 130,000 psi tensile strength. Tests were conducted in reversed bending with superimposed static bending in one instance and superimposed static torsion in another. In the latter tests the stresses

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[8] W. N. Findley, "Combined-Stress Fatigue Strength of 76S-T61 Aluminum Alloy with Superimposed Mean Stresses and Corrections for Yielding," *Technical Note No. 2924*, Nat. Advisory Comm. Aeronautics, May, 1953.

[9] W. N. Findley, "Effect of Range of Stress on Fatigue of 76S-T61 Aluminum Alloy Under Combined Stresses Which Produce Yielding," *Journal of Applied Mechanics*, Vol. 20, No. 3, Sept., 1953, pp. 365–374.

[10] W. N. Findley, F. C. Mergen, and A. H. Rosenberg, "The Effect of Range of Stress on Fatigue Strength of Notched and Unnotched SAE 4340 Steel in Bending and Torsion," *Proceedings*, Am. Soc. Testing Mats., Vol. 53, p. 768 (1953). (See author's closure on p. 788.)

[11] H. J. Gough, "Engineering Steels Under Combined Cyclic and Static Stresses," *The Engineer* (London), Nov. 11, 1949, p. 540. (See Fig. 11.)

applied did not exceed the static upper yield point at the endurance limit. In the former tests only the largest static bending stress caused stresses above the yield point.

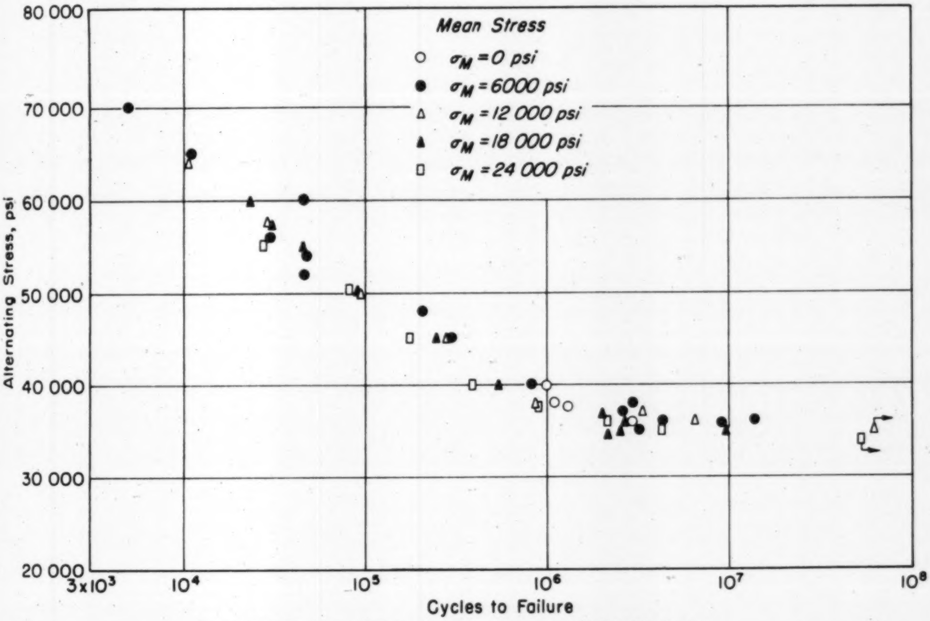

FIG. 7.—Fatigue Tests in Bending of SAE 1020 Steel.

In Gough's tests it was observed that the alternating bending stress at the endurance limit decreased slightly with increase in applied static stress—whether bending or torsion. The decrease was about 7 to 8 per cent for stress values which did not produce yielding. If the complementary normal stresses are computed from Gough's data, it is observed that the reduction in the endurance limit corresponding to the complementary normal stress is in nearly the same proportion whether the normal stress is produced by static bending or static torsion. On the other hand the sum of the three normal stresses corresponding to about the same reduction in endurance limit differs considerably between the tests having superimposed static bending and superimposed static torsion. Of course it remains nearly constant at about 70,000 psi for the static torsion case and increases in the static bending case to as much as 138,000 psi; yet for both static bending and static torsion the endurance limit decreased with increase in mean stress.

The above analysis of Gough's data would seem to support the complementary normal stress theory. It remains then to explain the data of Lea and Budgeon and Ono.

The data of Lea and Budgeon show that the addition of a static twisting stress to reversed bending stresses first causes a slight increase in endurance limit for nominal twisting stresses up to 50 per cent above the yield stress, followed by a marked reduction at higher stresses. A nickel steel (apparently in the annealed condition) showed a constant endurance limit with increase in static torsion followed by a marked reduction in endurance limit at nominal torsion stresses well above the yield point stress.

An examination of these data shows that the principal shear stress resulting from the combination of loadings was above the yield point of the material for all values of superimposed static torsion employed. Also the nominal stresses reported for the highest static torsion on the 0.28-in. diameter specimens would have caused very large plastic strains in these soft steels.

Another observation of significance to the present discussion is that the planes of the maximum principal shear stress resulting from the combination of bending and torsion loads, and hence the planes on which the greatest slip would occur during yielding, are different from the planes of principal shear stress resulting from the alternating bending.

In the light of the above observations, it may be that the data of Lea and Budgeon result from the following: The superimposed static torsion produces an increase in the complementary normal stress on planes of alternating principal shear stress. This, as in Gough's tests, produces a tendency toward a lower resistance to fatigue. At the same time yielding is produced in the tests reported by Lea and Budgeon on other planes as explained above. This yielding may have a work hardening effect for small strains whose strengthening effect on fatigue of the material may slightly exceed the weakening effect of the normal stress. At the large twisting strains produced by the higher static torsion, the material may have been damaged by introduction of micro cracks, resulting in reduced fatigue resistance, especially under the influence of the higher normal stresses.

If the above explanation is accepted, one may then ask why do superimposed static bending stresses not produce the same effect in these materials, namely an increase in endurance limit. The explanation seems to me to be that plastic yielding on planes which intersect planes of alternating principal shear planes produce increased resistance to fatigue on the latter planes, whereas plastic yielding on the same planes as the planes of alternating principal shear stress does not increase the resistance to fatigue or at least not to the same degree.

It has also been observed[12] that the endurance limit of SAE 1020 steel in bending does not decrease more than 3 per cent with increase in superimposed static bending for nominal stresses as much as 24,000 psi, as shown in the accompanying Fig. 7. This is in opposition to the axial load fatigue tests on the Haigh machine for mild steel cited by Lea and Budgeon (source not given) in which the endurance limit was shown to decrease by about 50 per cent with a static tension stress equal to the proportional limit.

The data reported by Ono is not available to me at present. It is reported, however, to be concerned with mild steel and to agree with the results reported by Lea and Budgeon.

In view of the above analysis, I feel that the normal stress acting on planes of alternating principal shear stress is likely to be the most important stress parameter causing changes in fatigue resistance of metals.

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[12] W. N. Findley, Unpublished data on fatigue of SAE 1020 steel under combined bending and torsion with superimposed mean stresses.

A SIMPLIFIED STATISTICAL PROCEDURE FOR OBTAINING DESIGN-LEVEL FATIGUE CURVES*

By E. H. Schuette[1]

Synopsis

The scatter inherent in most fatigue results makes multiple testing a "must" if suitable design stress levels are to be established. This same scatter, however, makes multiple testing an exceedingly tedious and time-consuming operation. The author suggests a procedure that will provide design-level curves with only a fraction of the testing time required for obtaining complete statistical data, and without mathematics. Illustrations of the method are provided by use of a large volume of simulated fatigue data, obtained in a novel manner.

An increasing number of laboratory fatigue investigations in recent years have made clear the statistical nature of fatigue life. It has become evident that testing of only a few specimens is an inadequate means of establishing suitable design stress levels, or even for making comparisons between materials. On the other hand, the use of large numbers of bars has so far been a tedious and time-consuming operation, requiring a knowledge of statistical mathematics and fraught with many difficulties.

Perhaps the major difficulty arises when some of the test failures at a given stress level do not occur within the maximum practicable time for which a test can be continued. These "run-outs" represent bars of unknown fatigue life, it being known only that the lives exceed some given value. Hence they are not amenable to inclusion in any simple statistical analysis. Some investigators have simply ignored the run-outs, and treated the remaining points as a complete statistical sample (**1**).[2] Others, dealing with similar problems and desiring a more rigorous approach, have utilized truncated-distribution analysis (**2, 3, 4, 5**.) In each case, however, the analysis has required that certain basic assumptions be made regarding the character of the frequency distribution of the underlying population from which the sample is drawn.

On the one hand, then, we have the time-honored procedure that consists of testing a relatively small number of specimens to determine an approximate mean curve; this procedure provides no real knowledge of the scatter that can be expected and consequently can be used in design only if modified by a liberal "factor of ignorance." On the other hand we have statistical methods capable of extracting maximum value from repetitive test data, but totally unsuited to the production of the high volume of results required of the usual industrial laboratory. The need for a middle-of-the-road approach is clear. To be most useful, such an approach should have the following characteristics:

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13–18, 1954.

[1] Metallurgical Laboratories, The Dow Chemical Co., Midland, Mich.

[2] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 864.

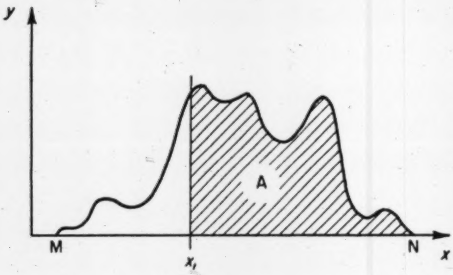


FIG. 1.—Assumed Frequency Distribution of the Variable, x.

1. It should be suitable for use by the average laboratory technician, without special training in advanced mathematical methods.
2. It should require little more actual testing time than present small-sample procedures.
3. It should result in a curve that has a definite meaning of significance to a designer.

The author proposes in this paper a method that meets in a high degree all three of these requirements.

DESCRIPTION OF THE METHOD

The proposed method is based on the obvious fact that if four nominally identical specimens are tested simultaneously under essentially identical conditions, that specimen having the least life potential will fail first. If, at this point, the remaining tests are stopped and the specimens discarded, considerable testing time will be saved over that required to run all of the tests to completion. At the same time, the single data point obtained, which will henceforth be called a "least-of-four" value, possesses significance far greater than a point taken from a single, independent test. It will be shown in the next section that a curve obtained from a series of least-of-four points is a curve that approximately 84 per cent of any future tests of the same material can be expected to exceed. It is this fact that makes the curve more suitable for design purposes than is the conventional mean curve.

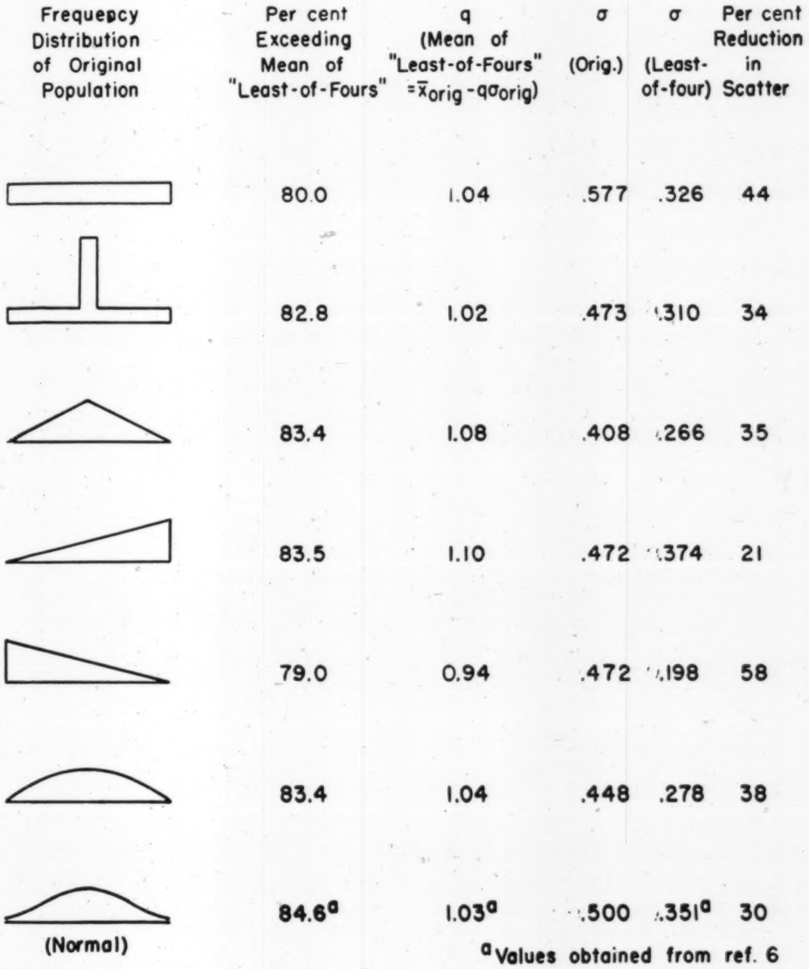
VALIDITY OF THE METHOD

Assume the possible values of some variable, x, to be distributed between M and N, with the relative probability of occurrence of each value given by some function, as shown in Fig. 1. Because the probability that any value, drawn from this assumed population of values, will lie between M and N is unity, that is, a certainty, it is fundamental that the total area under the distribution curve is unity. Similarly, the probability that any value drawn will lie between x_1 and N, that is, will be greater than x_1, is equal to the area, A, lying under the curve to the right of x_1 (see Fig. 1). This area is some value less than unity. It follows also that the probability that four consecutive values drawn from this population will all exceed x_1, is equal to A^4.

Now if the four consecutive values all lie to the right of x_1, then the least-of-four value is to the right of x_1; and if all four do not lie to the right of x_1, then the least-of-four value is to the left of x_1. The condition that would make x_1 the median of a large sampling of least-of-four values is that the probability of four consecutive individual values falling to the right of x_1 be precisely $\frac{1}{2}$, because this condition dictates that half the least-of-four values will lie to the right of x_1 and half to the left. Thus if x_1 is the median of least-of-four values,

$$\begin{aligned} A^4 &= \tfrac{1}{2} \\ A &= 0.8409. \end{aligned}$$

From this it is seen that approximately 84 per cent of the population sampled lies to the right of the median of least-of-four values. This conclusion is arrived at without imposing any limitations whatever on the nature of the original frequency distribution.



Frequency Distribution of Original Population	Per cent Exceeding Mean of "Least-of-Fours"	q (Mean of "Least-of-Fours" $=\bar{x}_{orig} - q\sigma_{orig}$)	σ (Orig.)	σ (Least-of-four)	Per cent Reduction in Scatter
	80.0	1.04	.577	.326	44
	82.8	1.02	.473	.310	34
	83.4	1.08	.408	.266	35
	83.5	1.10	.472	.374	21
	79.0	0.94	.472	.198	58
	83.4	1.04	.448	.278	38
(Normal)	84.6[a]	1.03[a]	.500	.351[a]	30

[a] Values obtained from ref. 6

FIG. 2.—Characteristics of "Least-of-Four" Drawings from Several Populations.

If a fatigue curve is obtained from least-of-four points, and sufficient points are obtained to define the curve with some confidence, the curve will be a representation of median least-of-four values, and thus it can be expected that 84 per cent of the material sampled will possess strength values lying above the curve. It is worth noting here that in the classic "normal" distribution, a value of the variable equal to the mean minus one standard deviation (σ) is a value that 84.13 per cent of the population exceeds. Thus, within very close limits, the median least-of-four value is also the mean-minus-1σ.

Thus far, we have been concerned only with the median. It will be of interest to discover whether the mean value is likely to differ by any great amount from the median, inasmuch as it could be argued that a curve drawn through a series of points may often more closely represent means than medians. This is the case when some function is ascribed to the curve and a least-squares fit is made to the data points. While no general statement regarding the significance of the mean of least-of-fours can be made, it is relatively easy to determine its significance in specific cases. This has been done for seven different assumed frequency distributions, with the results shown in Fig. 2. (For method of calculation, see Appendix.) From the percentage values in the first column, it is evident that even with very unlikely assumed distributions, departures from the 84-per cent value previously determined for the median are relatively small. For normal or near-normal distributions, deviations from this value are completely insignificant.

It is apparent also, from the second column in Fig. 2, that the mean of least-of-four values is not far removed from the mean-minus-1σ of the original population.

Using mean least-of-four values, it is possible to determine how much less scatter can be expected in least-of-four testing than would occur in conventional single-bar testing. The standard deviation can be readily calculated, and is listed in Fig. 2 for both the original population and the least-of-four values drawn from it. The final column shows the percentage reduction in scatter (that is, in standard deviation) to be expected. These values make clear that improved quality of data will be an automatic result of least-of-four testing.

RESULTS IN PRACTICAL APPLICATION

The foregoing has indicated that the least-of-four method is exceedingly simple to use and that it can give results of real design significance. It remains to be demonstrated that it is practical from the standpoint of testing machine hours required to obtain adequate data for a reasonably well defined *S-N* curve. To accomplish such a demonstration, it would be ideal if a large number of *S-N* curves could be run on nominally identical material by each of several methods, and a comparison made of quality of results and machine hours consumed in each case. This, however, would immobilize the average laboratory for several years, and even then the true characteristics of the material used, and the degree of control of these characteristics, would not be precisely known.

Complete control of characteristics and virtual identity of conditions can be assured by excluding the vagaries of natural phenomena and resorting to the familiar statistical procedure of drawing numbers from a bowl. The simulation of fatigue data in this fashion presents certain difficulties, but these are by no means insurmountable.

Numerous investigators have concluded that the frequency distribution of the logarithm of life at a given stress is very nearly normal. Current evidence, however, indicates that it cannot be precisely a normal distribution. If we accept the fact that the *S*-log *N* curve should at all points have a negative slope, and if we accept also that scatter of log *N* tends to be greater at low stresses than at high ones, we find these conditions incompatible with an assumption of normality. Assume, for example, a mean S-log N curve such as is illustrated in Fig. 3. Assume further that the scatter of log N, as characterized by the standard deviation σ, is greater at the low value, S_1, than at the higher value, S_2. The curves of mean-minus-1σ, or mean-minus-2σ, etc., may be quite acceptable; but if a sufficient number of standard deviations from the mean are taken, the curve must eventually assume a positive slope, as illustrated in Fig. 3 by the curve for mean-minus-$n\sigma$. This curve says, in effect, that the probability of an exceptionally early failure is greater at low stresses than at high.

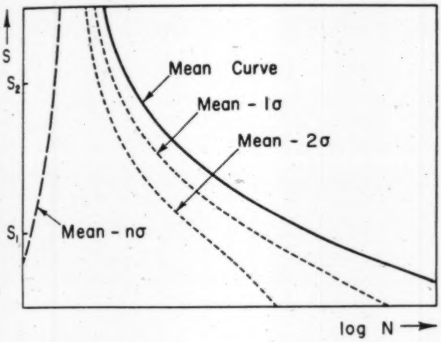


FIG. 3.—Results of Assuming Normal Frequency Distribution of Log N.

The above *reductio ad absurdum* will be avoided if it is assumed that the distribution of log N about its particular mean value is the same at all stress levels. An equally effective assumption, however, which also allows for the observable fact that the spread in values of log N is greater at lower stresses, is that the distribution of 1/log N about its own mean remains constant at all stress levels. This latter assumption was used herein to simulate a large volume of fatigue data. The degree of scatter was based on studies of data from actual materials, but the actual curve employed is purely hypothetical.

It was assumed that a test material had a mean curve representing the relationship between the stress, S, and the variable 1/log N, as given in Table I. It was further assumed that the distribution of values of 1/log N about the mean at any stress level was essentially normal and independent of the stress. This distribution was represented by 199 small tabs bearing the numbers given in Table II. These tabs were shaken up in a paper bag, and a "fatigue test" was run in the following fashion:

TABLE I.—DATA OF HYPOTHETICAL MEAN CURVE OF S *versus* 1/LOG N.

S	$\overline{1/\log N}$	Corresponding Value of log $\overline{N}$
40.....	0.2315	4.32
35.....	0.2065	4.85
30.....	0.1731	5.78
27.....	0.1466	6.82
25.....	0.1249	8.01
24.....	0.1125	8.89
23....	0.0988	10.12

1. Select a stress, and record the mean value of 1/log N.

   (Example: $S = 30$, $\overline{1/\log N} = 0.1731$)

2. Draw a number from the bag, and add it, with proper regard for sign, to 1/log N.

   (No. drawn: -0.0213; $0.1731 - 0.0213 = 0.1518$)

3. Convert to log N by inversion. This is the test result.

   ($1/0.1518 = \log N = 6.59$; $N = 3{,}890{,}000$ cycles)

Each number was returned to the bag and the contents were thoroughly shaken before the next drawing was made.

"Fatigue tests" were run in this fashion in groups of four, and in each group the lowest was selected as the least-of-four value. (The other three were also tabulated for use in subsequent calculations.) The run-out limit was established at 20,000,000 cycles. Thus, if any drawing indicated greater life than this, the point was recorded as a run-out. Twenty fatigue curves were obtained, using eight groups of four "test bars" for each curve. Stress values for the "testing" were selected two at a time, to simulate the laboratory condition of keeping eight machines in operation. The selections were made as if by a machine operator. That is, the 20 curves were each begun with different pairs of stresses, and subsequent choices of stress were made on the basis of the data thus far obtained, without being influenced by any foreknowledge of the correct position of the curve. Examples of the curves obtained are shown in Fig. 4. It should be pointed out here that the assumed inherent scatter in this hypothetical material was abnormally great. Since assumption of small scatter would insure good results, it seemed a fairer test of the method to work at the other end of the scale. Thus, in some cases, it might be said the curves were not adequately determined with only eight points. For consistency, however, the program was limited to this number.

TABLE II.—DEVIATIONS FROM MEAN VALUE OF 1/LOG N USED IN SIMULATING TEST DATA.

0.0768	0.0425	0.0312	0.0232	0.0167	0.0110	0.0056	0.0004
0.0693	0.0415	0.0306	0.0228	0.0163	0.0106	0.0052	0.0000
0.0646	0.0405	0.0300	0.0223	0.0159	0.0102	0.0049	−0.0004
0.0610	0.0395	0.0294	0.0218	0.0155	0.0098	0.0045	−0.0007
0.0582	0.0386	0.0288	0.0213	0.0151	0.0094	0.0041	−0.0011
0.0559	0.0378	0.0282	0.0209	0.0147	0.0091	0.0037	....
0.0538	0.0370	0.0276	0.0204	0.0143	0.0087	0.0034	(Identical,
0.0519	0.0362	0.0270	0.0199	0.0139	0.0083	0.0030	except for
0.0502	0.0354	0.0264	0.0194	0.0134	0.0079	0.0026	sign, with
0.0487	0.0347	0.0259	0.0190	0.0130	0.0075	0.0022	positive
0.0473	0.0340	0.0253	0.0185	0.0126	0.0071	0.0019	values.)
0.0459	0.0333	0.0247	0.0181	0.0122	0.0067	0.0015	....
0.0447	0.0326	0.0242	0.0176	0.0118	0.0064	0.0011	−0.0693
0.0435	0.0319	0.0237	0.0172	0.0114	0.0060	0.0007	−0.0768

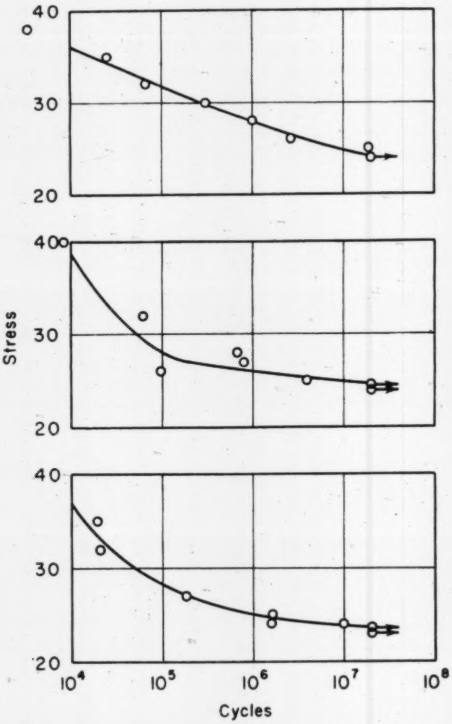


FIG. 4.—Examples of Fatigue Curves Obtained from Simulated Data.

The fatigue curves obtained were of course not perfectly consistent. To check their general conformance with the correct curve, an envelope of all 20 curves was prepared. This is compared with the correct curve in Fig. 5. The effect of the large scatter assumed is evident, but fair conformance was obtained nonetheless. It is significant to note that in no case did the least-of-four curves go as high as the mean curve for the material.

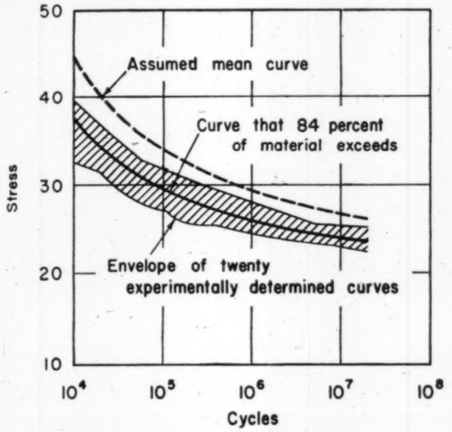


FIG. 5.—Envelope of Experimental Curves Compared with Correct Curve.

VALIDITY OF THE DRAWINGS

In all, 640 drawings were made from the population indicated by Table II, for purposes of running the simulated fatigue tests. It is relatively simple to predict the theoretical result of such drawings, and it will be of interest to compare these with the results actually obtained.

The initial population has a mean value of zero, and a standard deviation of 0.0289. The 640 drawings gave a mean value of 0.0007, and an estimated standard deviation of 0.0281. It can be concluded from this comparison that the drawings were adequately representative. Calculations further indicate that least-of-four values drawn from the given population might be expected to show a mean of 0.0299, with a standard deviation of 0.0199. Actual results gave a mean of 0.0311 and an estimated standard deviation of 0.0189. The adequacy of this check is evident when it is realized that a difference of 0.0010 in 1/log N represents only 80,000 cycles out of a million, or 360 out of 10,000.

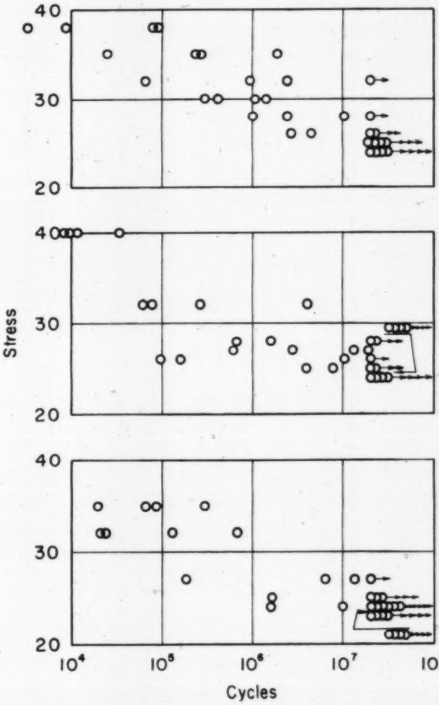


FIG. 6.—Effect of Including All Points in Each Group on Data of Fig. 4.

REDUCTIONS IN TESTING TIME

A simplified approach to any given problem can be justified only if it provides significant savings of time or effort. The savings in technical effort offered by the least-of-four approach are quite obvious, inasmuch as absolutely no mathematics, or even graphical analysis, is required. A measure of the saving in testing time is available from the simulated fatigue tests that were performed. It will be of interest to consider the actual number of machine-cycles consumed in preparing the 20 curves by various methods.

If all four tests in each group had been run to completion—with the condition that testing would in any case be stopped after 20,000,000 cycles—a total of 5527 × 10^6 machine-cycles would have been required. On the other hand, with all four tests stopped as soon as one test was completed, only 2656 × 10^6 machine-cycles would be consumed. This represents a 52 per cent reduction in testing time. Under these conditions, however, the value of completing all the tests up to the run-out limit would be partially lost by virtue of the presence of run-outs in many of the groups. The curves of Fig. 4 are repeated in Fig. 6 with the additional test points from each group of four included. These are representative of the 20 curves obtained. Over all, 60 per cent of the groups of four included at least one run-out. Thus the value of 60 per cent of the data would be seriously impaired.

TABLE III.—COMPARISON OF SIMPLIFIED METHODS OF ANALYZING DATA.
(Top Curve of Fig. 4)

Stress	Log N						Error in Log N	
	Least-of-4[a]	Additional Values[a]			Correct 84 per cent Value	Mean-minus-half-range	Least-of-4	Mean-minus-half-range
38..........	3.53	3.95	4.90	4.94	3.97	3.63	−0.44	−0.34
35..........	4.40	5.37	5.42	6.27	4.23	4.43	+0.17	+0.20
32..........	4.82	5.97	6.39	(7.59)	4.60	4.81	+0.22	+0.21
30..........	5.48	5.62	6.04	6.15	4.93	5.49	+0.55	+0.56
28..........	6.00	6.39	7.01	(8.05)	5.38	5.84	+0.62	+0.46
26..........	6.43	6.64	(7.42)	(12.45)	6.02	5.22	+0.41	−0.80
25..........	7.27	(8.91)	(10.53)	(10.67)	6.46	7.64	+0.81	+1.18
24..........	(8.25)	(9.23)	(10.01)	(15.34)	7.02	7.16	+1.23	+0.14

[a] Values shown in parentheses would be run-outs if all tests were stopped after 20,000,000 cycles.

Among the remaining 40 per cent of the groups—those of which all four tests would show definite and known life values—the time comparison in favor of the least-of-four method is surprisingly good. For these tests, running all four bars to completion would consume 300.8 × 10^6 machine-cycles, while stopping after the first failure would reduce this figure to 32.7 × 10^6 machine-cycles, a saving of 89 per cent. The significance of this saving is better understood when it is realized that these groups are the only ones for which the completion of all the tests offers any great improvement in the usefulness of the data obtained. If one or more run-outs are included, submitting the data to mathematical treatment is exceedingly difficult at best.

It was planned at the outset to make a direct comparison of the results obtained by the least-of-four method with those obtained by other available relatively simple approaches in which all four values are used. Such a method would be the calculation of the mean and subtraction therefrom of a specified fraction of the range (from lowest to highest), as described by Lord (7). As given, this procedure expresses the significance of the results in terms of each individual group of four, rather than the mean or median results from several groups. A direct comparison is possible, however, if the mean minus half the range is used, for one can conclude intuitively that this will, in a symmetrical population and over a large sampling, give the same average value as the least-of-four.

The comparison is of course possible only if the mean and range are known. This requires that the arbitrary limit on test time be removed, and that all tests be run to failure. One set of results obtained under these conditions is tabulated in Table III. The data in the first five columns are the same as those plotted in the top graph of Fig. 6, with the exception that the full potential lifetime of every "specimen" is given. The sixth column lists the abscissa values of a correct curve that 84 per cent of the material will exceed. The final two column show the errors realized in the least-of-four and mean-minus-half-range values.

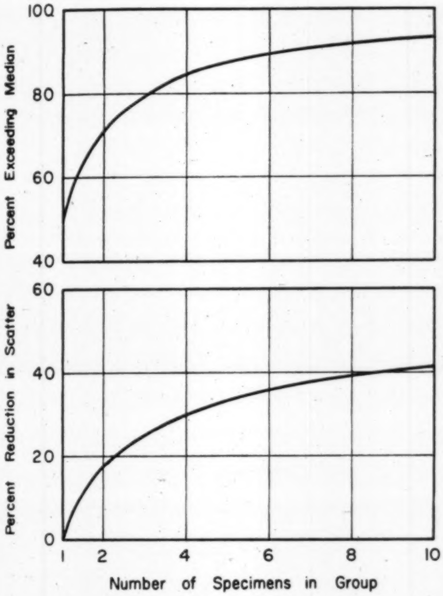


FIG. 7.—Effect of Number of Specimens on Results of "Least-of-*n*" Testing.

It would appear from the errors involved in this particular case that the advantage of having all four points lies in flexibility, since other than the 84-per cent limit can be estimated, rather than in improved accuracy. The practical obstacles to getting all four points, however, may be insurmountable. Note, for example, that the final test result listed would take 2,190,000,000,000,000 cycles to complete. At 1400 cycles per min, this amounts to approximately 3,000,000 years of continuous testing. This is by no means the longest test that would be involved in the 20 *S-N* curves that were constructed.

These figures are of course dependent upon the amount of scatter the material was originally assumed to show. As the four bars in a group tend toward equal lifetimes, the amount of time saved by stopping all tests after the first failure is reduced; but so is the need for refinements of technique. If there were no scatter, a single test at each stress level would suffice.

A further potential saving immediately suggests itself. If suitable fixtures can be provided for testing four randomly selected bars in tandem (or possibly, with equalizing fixtures, in parallel), then the four bars could be tested with the total machine-cycles consumed being equal to the cyclic lifetime of the first bar to fail, rather than four times that amount. Such an arrangement has been suggested for creep-to-rupture testing (8), but to the author's knowledge, its use in fatigue has never been checked. Inertia effects might make it very difficult to attain the same stress in all four bars, but the potential 75-per cent additional time reduction should make the method worth at least some preliminary trials.

CHOICE OF NUMBER OF SPECIMENS

All of the foregoing discussion has been based on a choice of four as the number of bars in a group. There is no special magic about this particular number; it is merely the author's idea of a proper compromise among several conflicting demands. The desire for adequate sampling would lead one to a choice of groups containing large numbers of specimens. The desire to have the resulting fatigue curve represent a level that most of the material will exceed also works in this direction. But practical requirements limit one's freedom. It is important, if the full potential savings are to be realized, that the number of bars in a group be no greater than the number of machines available, and that the number be held to a figure that will not impose a prohibitive requirement for specimen preparation.

Figure 7 shows the reduction in scatter achieved by various numbers of specimens in each group, assuming the underlying population is normally distributed. The figure also shows, for each case, the percentage of the original population that can be expected to exceed the resulting curve. It can be seen that the incremental improvement per added specimen gets rather small as the number is increased beyond four. For less than four, however, the resulting curve can hardly be called a suitable design level. These considerations, coupled with the convenient fact that use of four specimens results in a curve representing for all practical purposes the mean-minus-1σ, have led to the choice of four by the author. If suitable methods were developed for parallel testing in a single machine, then the practical considerations of load-equalizing devices would add further weight to the use of four specimens.

It might be worth pointing out that investigations that may have been carried out with more than four bars at each stress level can be readily adapted to give the same curve as would result from least-of-four testing. Suppose five specimens have been tested, and gave log-lives, ranked in increasing order, of L_1, L_2, L_3, L_4, and L_5. What, then, is the most likely least-of-four value? In a process of random selection of four specimens, any one of the five might have been left out. If L_2, L_3, L_4, or L_5 had been eliminated, L_1 would have been the least of the four remaining. If L_1 had been left out, L_2 would have been the least of the remaining four. Thus, occurrence of L_1 as the least-of-four is four times as likely as L_2, and the appropriate least-of-four value is given by

$$\frac{4L_1 + L_2}{5}$$

In like manner, and using similar notation, it is deduced that if six bars are tested, the appropriate least-of-four value is given by

$$\frac{10L_1 + 4L_2 + L_3}{15}$$

Similar formulas could be developed for more than six values, but presumably if so many tests are run, it is for the purpose of conducting a more complete statistical analysis, and such short-cut methods would have little value. It is worth noting, moreover, that the above formulas imply certain assumptions regarding the underlying frequency distribution, and cannot be extended indefinitely.

An analysis on the rectangular distribution shown at the top of Fig. 2 indicates that running five tests and converting to the most likely least-of-four value in the above fashion leads to a scatter (standard deviation) 52 per cent less than that of the original population. This compares with 44 per cent reduction when only four specimens are used in each group.

CONCLUSIONS

In any testing program in which appreciable scatter is to be reckoned with, and in which the results can become available to the operator in ordered fashion, it is obvious that a process of starting a number of identical tests simultaneously and stopping as soon as one specimen fails will require less time than if all the tests were carried to completion. It has been shown herein that a definite significance can be ascribed to the results of such a process, and that this significance is independent of the nature of the underlying frequency distribution from which sampling is being done. Simulated fatigue-test data demonstrate the use of the "least-of-four" method of testing, and give an idea of the magnitude of the time saving made possible.

The "least-of-four," or, in general, any "least-value" method, is not limited to fatigue testing in its usefulness. Life testing of any kind seems to be plagued by scatter, and in many fields, for example, simple electrical equipment or stress corrosion, the testing of several samples simultaneously may require little more time or effort than if single samples were used.

APPENDIX

CALCULATIONS FOR ARBITRARY POPULATIONS

As an example of the method of calculating various characteristics of the distributions of least-of-four values selected from arbitrary populations, the right triangular distribution, shown fourth in Fig. 2, is selected. If the limits on the variable, x are taken as 0 and 2, then the frequency-distribution function is

$$y = \frac{x}{2} \ldots\ldots\ldots\ldots\ldots (1)$$

The probability that any single value drawn from this population will exceed some value, x, is given by the area under the frequency-distribution curve to the right of x. Thus,

$$p_{>x} = \int_x^2 \frac{x}{2}\,dx = 1 - \frac{x^2}{4} \ldots\ldots (2)$$

The probability that four consecutive values drawn will all exceed x is then given by

$$p_{4>x} = (p_{>x})^4 = \left(1 - \frac{x^2}{4}\right)^4 \ldots\ldots (3)$$

Now the probability that x is precisely the lowest of the four values, symbolized by $p_{x/4}$, is given by the amount of decrease in the above value in going from x to $x + dx$. Thus, it is the negative of the derivative of $p_{4>x}$ with respect to x:

$$p_{x/4} = -\frac{d\left(1 - \frac{x^2}{4}\right)^4}{dx} = 2x\left(1 - \frac{x^2}{4}\right)^3 \ldots (4)$$

The mean of least-of-four values is obtained by summing up the products of all incremental x-values with their respective probabilities, and dividing by the sum of the probabilities, which, by definition, is unity. Therefore

$$\bar{x} = \int_0^2 2x^2\left(1 - \frac{x^2}{4}\right)^3 dx = \frac{256}{315} \ldots (5)$$

From Eq 2, the area lying to the right of this value of x is

$$1 - \frac{(256/315)^2}{4} = 0.835$$

Thus, 83.5 per cent of the initial population exceeds the mean of all least-of-four drawings from the population.

The mean square of least-of-four drawings is obtained by multiplying the probability values of Eq 4 by x^2 instead of x, and again integrating as in Eq 5, from which

$$\overline{x^2} = \tfrac{4}{5}$$

Then the standard deviation of least-of-four values is given by

$$\sigma = \sqrt{\overline{x^2} - (\bar{x})^2} = \sqrt{0.8000 - 0.6605} = 0.374 \quad (6)$$

For the initial population, the mean, mean square, and standard deviation are obtained as follows:

$$\bar{x} = \int_0^2 \frac{x^2}{2}\,dx = \frac{4}{3} \quad (7)$$

$$\overline{x^2} = \int_0^2 \frac{x^3}{2}\,dx = 2 \quad (8)$$

$$\sigma = \sqrt{2 - \frac{16}{9}} = 0.472 \quad (9)$$

The value of q in Fig. 2, the ratio of the difference in means between the original and least-of-four populations to the standard deviation of the original, is now obtained as

$$\frac{\frac{4}{3} - \frac{256}{315}}{0.472} = 1.10$$

If limits other than from 0 to 2 had been used for the initial population, the values of mean, mean square, and standard deviation would of course be altered, but the relative values would be the same. Thus, this change would not affect the value of q, the percentage of the original population that exceeds the mean of least-of-fours, nor the percentage reduction of the standard deviation brought about by the least-of-four technique.

The other finite populations in Fig. 2 were handled in the same manner, using appropriate equations for the indicated frequency distribution. Should the reader wish to make check calculations, he will need to know that the next-to-last distribution in Fig. 2 is a parabola, following, between the limits $x = -1$ and $x = 1$, the equation

$$y = \tfrac{3}{4}(1 - x^2) \quad (10)$$

REFERENCES

(1) E. Epremian and R. F. Mehl, "Investigation of Statistical Nature of Fatigue Properties," Nat. Adv. Comm. Aeronautics, *Technical Note 2719*, June, 1952.

(2) Max Halperin, "Maximum Likelihood Estimation in Truncated Samples," *Annals of Mathematical Statistics*, Vol. 23, pp. 226–238 (1952).

(3) P. H. Jacobson, "The Relative Power of Three Statistics for Small Sample Destruction Tests," *Journal*, Am. Statistical Assn., Vol. 42, pp. 575–584 (1947).

(4) J. E. Walsh, "Some Estimates and Tests Based on the Smallest Values in a Sample." *Annals of Mathematical Statistics*, Vol. 21, pp. 386–397 (1950).

(5) B. Epstein and M. Sobel, "Life Testing,' *Journal*, Am. Statistical Assn., September, 1953.

(6) L. H. C. Tippett, "On the Extreme Individuals and the Range of Samples Taken from a Normal Population," *Biometrika*, Vol. 17, pp. 364–387 (1925).

(7) E. Lord, "The Use of the Range in Place of the Standard Deviation in the "t" Test," *Biometrika*, Vol. 34, pp. 41–67 (1947).

(8) W. J. Youden, "Statistics and Planning Tests at Elevated Temperatures," *Proceedings*, Soc. Exptl. Stress Anal., Vol. 11, No. 2, pp. 219–222 (1954).

DISCUSSION

MR. IAN D. EATON[1] (*presented in written form*).—In my opinion, Mr. Schuette has presented an applicable approach to the use of statistical analysis in fatigue testing. To be sure, there are some cases, depending upon the end use of the fatigue test results, when the mean curve and variance are probably more important than the least-of-four results suggested. The time saving shown by Mr. Schuette's analysis surely indicates that his suggestion warrants attention and study. His method of obtaining 640 test results is of considerable interest.

As pointed out by Mr. Schuette, the amount of time saving is dependent upon the amount of scatter existing. At Aluminum Research Laboratories we have some test data in which 3 to 5 specimens from a single lot of material were tested at each of several stress levels. The results are shown in the accompanying Fig. 8. When these data are analyzed on the basis of the least of 3 to 5, as the case may be for the various stress levels, it is found that, if individual machines are used, the time saving by the "least-of" method is 49 per cent of the machine time required to obtain the entire lot of test data. Had these data been obtained by testing the 3 to 5 specimens in tandem in one machine and had the testing been stopped at the first failure, the machine time saving would have amounted to 83 per cent. It is difficult to evaluate the actual over-all time saving because of such factors as time required to insert specimens in the machines and elapsed time between the end of one test and the beginning of the next, which may be more than 63 hr if there is no one on duty between 5 pm Friday and 8 am the following Monday. Therefore, the time saving is considered on the basis of actual running time of the machines.

As early as 1942[2] the Aluminum Research Laboratories reported results of tests in which four specimens were loaded in parallel, and thus the test results reported were those representing a least-of-four value. Additional such test results have been reported.[3] These test results have recently been expanded to include results, now being prepared for publication by the National Advisory Committee for Aeronautics, in which tests were made on single joints as well as on four joints in parallel. It developed that in each case the specimen tested singly produced results which are entirely consistent with those obtained by testing four specimens at a time. An illustration of a typical curve, one of three in the publication, from these additional tests is shown in the accompanying Fig. 9; and

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[2] E. C. Hartmann and G. W. Stickley, "Summary of Results of Tests Made by ARL of Spot-Welded Joints and Structural Elements," Nat. Advisory Comm. Aeronautics Technical Note 869; also Supplement, *Journal*, Am. Welding Soc., April, 1947, p. 215s.

[3] Marshall Holt, "Results of Shear Fatigue Tests of Joints with $\frac{3}{16}$-in. Diameter 24S-T31 Rivets in 0.064-in. Thick Alclad Sheet," Nat. Advisory Comm. Aeronautics Technical Note 2012.

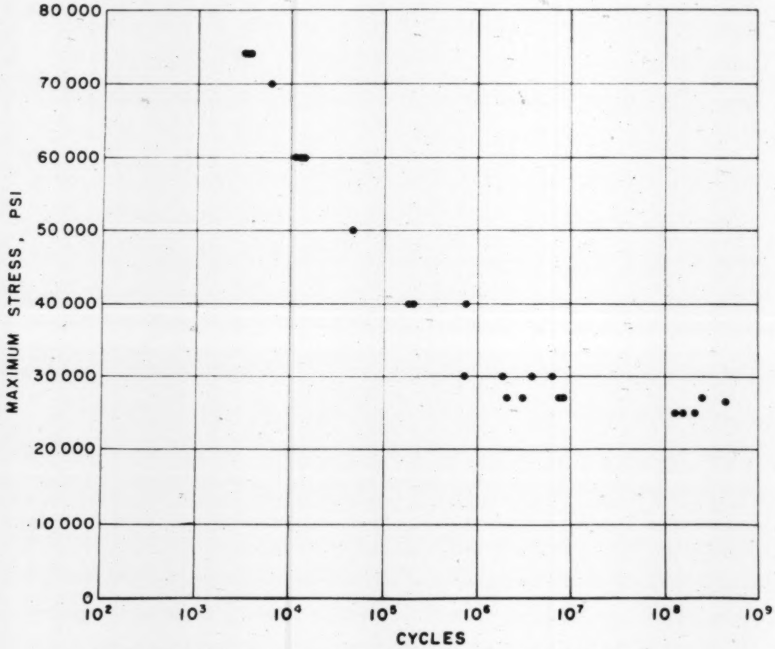

FIG. 8.—Rotating-Beam Fatigue Test Results for 75S-T6 Rod.

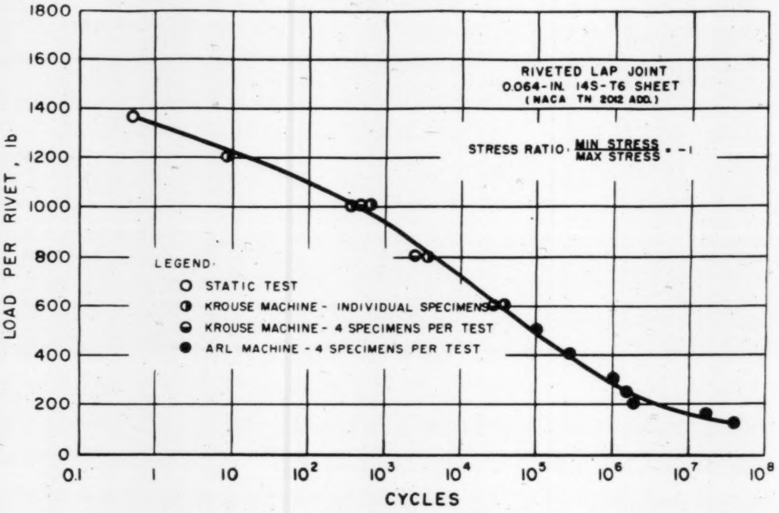

FIG. 9.—Direct-Stress Fatigue Test Results.

it would appear therefrom that there would be little time saved if testing were done in separate machines by limiting the test results to the least-of-four value rather than obtaining the results for all four specimens. In general, it would appear from our work at Aluminum Research Laboratories that test results for notched and component specimens are subject to less scatter in results than smooth specimens; hence the least-of-four method, when applied to component testing, would not be expected to show as large time saving as for smooth specimen testing.

Perhaps had Mr. Youden, in his paper referred to by Mr. Schuette (8), expanded his suggestion, instead of calling it "something of a hair-brained idea," it would not have been lost in his discussion of statistics and would have received the attention that Mr. Schuette's paper will.

The suggestion by Mr. Schuette and Mr. Youden of testing in tandem, using one machine to test three or four specimens at one time appears to have a great deal of merit. They each suggested that the testing be restricted to the least value obtained from such a test, but the method appears to warrant some consideration in tests designed to determine the amount of scatter. Mr. H. J. Maier in "Reducing Cost of Fatigue Testing"[4] used a multiple test-section cantilever-beam specimen at a single load to accumulate cycles at lower stress levels while fracturing that section of the specimen at higher stress levels. When the section of the specimen subjected to the highest test level failed, he proceeded to grip the next section and so on until final fracture of the section nearest the loading end. Neglecting run-out tests, the time saving was about 30 per cent over that required to test the individual specimens.

As suggested by Schuette and Youden, it would seem feasible to test specimens which are alike four at a time in one machine and at a constant load. Some machines, of course, are much more adaptable for this type of testing than others, but particularly in some machines it should not present very much difficulty. It is proposed that the results for all four specimens tested to failure in tandem be reported rather than only the least-of-four results. Some extra care may be required in order to assure that the failure of one specimen does not affect the fatigue strength of the other specimens which remain to be tested. When the data shown in Fig. 8 are analyzed in this respect, it is found that all of the test data could be obtained by testing identical specimens in tandem 3 to 5 at a time, depending on the number of data points available at each stress level, with a saving of 40 per cent of the testing time. This compares favorably with the amount of time saving shown by Mr. Schuette and is almost as great as the 49 per cent based on the least-of-3 to 5 data points tested in separate machines. The method does have the further advantage that each specimen machined is tested to destruction.

It is to be expected that, as a result of Mr. Schuette's paper, additional test results will be presented which indicate the influence his proposal has in the field of lifetime testing of many types.

MR. FRANK A. MCCLINTOCK.[5]—The least-of-four may also be interpreted by noting that if first four specimens and then a fifth are tested, the fifth is equally likely to lie in any of the five positions intermediate to a pair of, below, or above the other four. Thus if one always states that any future observation will lie above the lowest of the sample of four, one will be right four times out of five. One may say, then, that the least of four is a lower 80 per cent confidence limit for any future single observation.[6]

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[4] *Machine Design*, Sept., 1949.

[5] Assistant Professor of Mechanical Engineering, Massachusetts Institute of Technology, Cambridge, Mass.

Another interpretation is that the least-of-four is a limit such that in the long run the average fraction of the population lying above the broken line determined by the least-of-fours is 80 per cent.

A third interpretation is that the least-of-four is the lower 93.75 per cent confidence limit for the median of the population.[7] These alternative interpretations of the least-of-four do not contradict that proposed by the author, and indeed the first two are similar enough to the author's to be equivalent for practical purposes.

TABLE IV.—REDUCTION IN COST DUE TO LEAST-OF-FOUR PROGRAM.

	Example 1		Example 2	
Program	Ordinary	Least-of-four	Ordinary	Least-of-four
Specimens	640	640	256	256
Cycles	5527×10^6	2656×10^6	300.8×10^6	32.7×10^6
Specimen cost	$2560	$2560	$1024	$1024
Cycles cost	$3130	$1500	$170	$18
Total cost	$5690	$4060	$1190	$1040

But the use of the least-of-four is not entirely adequate for all practical purposes. Certainly design should be based on a 99.9 per cent or higher, rather than an 80 per cent confidence basis. Such estimates can be obtained from a sample of four,[8, 9] but require a knowledge of the lives of all four specimens, as well as some assumption regarding the shape of the distribution. In comparing two alloys, for example, one which looks inferior on a least-of-four basis may actually be superior for practical use if its variability is less. In addition, the size effect due to variability in the material will be less. Thus if tests are stopped at the least-of-four point, valuable information may be lost.

The reduction in cost due to stopping tests may be less than at first imagined. Assume, for example, that specimens costing $4 each, including set-up time, are tested individually in machines costing $1500 each and occupying 20 sq ft of laboratory space at a cost of $4 a sq ft per year. Assume that the machines are in operation 8000 hr per year at 1400 rpm and are amortized at a flat 20 per cent per year. Thus the machine and space costs are $0.57 per million cycles. The reductions in cost due to the use of the least-of-four program for the two examples given by the author are presented in the accompanying Table IV. Of course, similar computations should be made for whatever research program is at hand, but these results do indicate that the reduction in cost may not be very large compared to the loss of information and the possibility of using other statistical techniques. Furthermore, less variability in the specimen lives and the use of high-speed, rotating-beam machines would make the reduction in cost even less significant.

MR. ROBERT W. CORNELL[10] (*by letter*).—Mr. Schuette should be congratulated for his interesting paper on a simplified procedure for obtaining design-level fatigue life curves. This method should be useful when an S-N curve at approximately the lower 1σ level or better is satisfactory for design purposes and when the possibility of multiple testing exists coupled with an adequate specimen supply. Of particular interest was his method of simulating fatigue data, which should prove very helpful in checking other statistical analysis methods and test procedures.

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[6] S. S. Wilks, "Determination of Sample Sizes for Setting Tolerance Limits," *Annals of Mathematical Statistics*, Vol. 12, p. 91 (1941).

[7] K. R. Nair, *Sankhya* (Indian Journal of Statistics), Vol. 4, Part 4, March, 1940, p. 551.

[8] C. Eisenhart, Hastay, and Wallace, "Selected Techniques of Statistical Analysis," McGraw-Hill Book Co., Inc., New York, N. Y., Chapter II (1947).

[9] J. Lieblein, "A New Method of Analyzing Extreme-Value Data," Nat. Advisory Comm. Aeronautics Technical Note 3053, January, 1954.

[10] Senior Analytical Engineer, Hamilton Standard Division, United Aircraft Corp., Windsor Locks, Conn.

The saving of testing time realized by the least-of-n method depends greatly on the number of specimens that can be tested at one time. If the n specimens can be tested simultaneously, then all n tests can be stopped when the first specimen breaks, thereby realizing the full time saving. In some instances this can be accomplished by testing all the specimens on one machine or by testing them on two, four, or more machines at the same time. It has been the practice at Hamilton Standard to test up to 6 scale and full-size specimens at a time on one electromagnetic vibration machine. By tuning the full-size specimens and by proper mating of the scale specimens, it has been possible to test the specimens at stresses within a few per cent of each other. However, for certain loadings it has not been feasible to test more than one at a time. In instances like this the small time saving advantage of the least-of-n method would probably be outweighed by the incomplete data obtained. In general, the time saving advantages are made at the expense of obtaining the mean life and the standard deviation which provides the basis for extrapolation of the data to life curves at lower probability levels. This latter factor is very important in cases where there are large variations in the lives at a given stress level and where a single failure may involve great hazard. The least-of-n method gives no information concerning the deviation, so that one has no idea how good the values are designwise, even though they represent approximately the lower 1σ or better limit. Also, many groups of n specimens must be tested in order to be sure of obtaining the mean curve which represents approximately the lower 1σ or better life curve. Figure 5 shows that there is considerable error in assuming the lower 1σ life curve is given by the earliest failures of only a few groups of four.

The author is concerned primarily with the S-N curve in the life or time-strength region. Several years ago I considered the closely related problem of determining the endurance limit with a given degree of accuracy, using the least amount of test time. The procedure employed statistical principles and was based on the fact that two factors determine the accuracy in defining the endurance limit —sample size, n, and number of test cycles, N. In order to determine the endurance limit of a material or structure at Hamilton Standard, we often use the loading-up method of testing in which the specimens are tested a given number of cycles, N, at each of increasing stress levels until one or more specimens fail at one of the levels. Generally, the highest level at which no failures occur is designated the endurance limit, or more precisely, the fatigue strength associated with N cycles. If time and expense permit, we usually continue to test the specimens until all have failed so that a plot of probability of failure *versus* stress can be made.

The degree of confidence in the above defined endurance limit being the true endurance limit (at a given probability level) is a function of the sample size, n, and the number of cycles, N, that the specimens were tested at each stress level. It can be shown that for a universe of say, then, that the least of four is a lower 80 per cent confidence limit for any future single observation.[6]

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The degree of confidence in the above defined endurance limit being the true endurance limit (at a given probability level) is a function of the sample size, n, and the number of cycles, N, that the specimens were tested at each stress level. It can be shown that for a universe of

$\bar{n}$ specimens, the confidence, P_η, that the universe has a probability of failure of $\bar{p}$ or less at a stress level at which no specimens failed out of a sample of n specimens is

$$P_n = 1 - \frac{(n - \overline{np})!\,(\bar{n} - n)!}{\bar{n}!(\bar{n} - \overline{np} - n)!} \ldots\ldots (1)$$

For an infinite universe, that is $\bar{n} \rightarrow \infty$, the accompanying Eq 1 simplifies to the familiar expression

$$P_n = 1 - (1 - \bar{p})^n \ldots\ldots\ldots (2)$$

Thus, if n specimens are tested for an infinite number of cycles at each stress level, one would have a confidence of P_η that the universe had a probability of failure of $\bar{p}$ or less at the highest stress level at which none of the specimens failed. However, because the specimens were tested only N cycles at each stress level, the over-all confidence, P, that the universe has a probability of $\bar{p}$ or less is decreased by the possibility that not all the failures at a given level would occur before N cycles. Therefore,

$$P = P_N \cdot P_\eta \ldots\ldots\ldots\ldots (3)$$

where P_N is the probability of all failures having occurred by N cycles. The value of P_N can usually be approximated by making a P *versus* log N plot for the stress level at which failures first occur, from the results of a pilot test, or from previous data; see the accompanying Fig. 10. In general, the value of P_N will be optimistic.

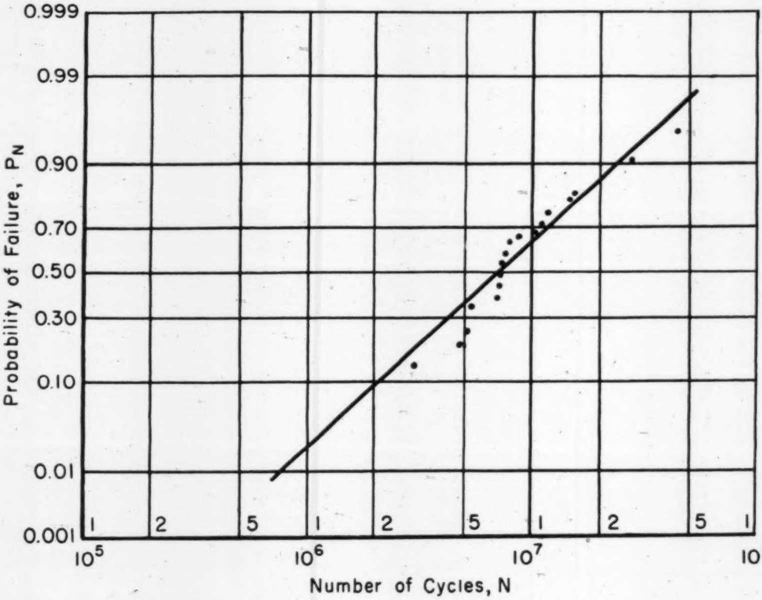

FIG. 10.—Probability of Failure in Given Number of Cycles of Stress Near Endurance Limit.

Now, the total machine test time, Nn/a, where a is the number of specimens tested per machine, for a confidence, P, that the universe has a failure rate of $\bar{p}$ or less can be found by selecting values of n and N such that $P = P_\eta \cdot P_N$. Assuming various sample sizes, n, one can calculate by Eq 1 or 2 the confidence, P_η, that the universe has a probability of failure of $\bar{p}$ or less if no failures are obtained at a stress level. The required values of P_N, consistent with the over-all desired degree of confidence, P, is then obtained by dividing P by P_η. The number of cycles, N, that the specimens should be tested at each level can then be found from the P *versus* log N plot mentioned above. If this procedure is repeated for various sample sizes and the machine test time is plotted against sample size for a given over-all degree of confidence that the universe has a probability of failure of $\bar{p}$ or less, a curve like that shown in accompanying Fig. 11 will be obtained. From such a plot the minimum test time, n_oN_o/a, is determined, which is obtained by testing n_o specimens for N_o cycles at each stress level. If this process is repeated for other over-all degrees of confidence and probabilities of failure of the universe, the results from Fig. 11 for the minimum machine test time, n_o, N_o and $\bar{p}$, can be cross-plotted as shown in Fig. 12. This figure indicates that there is an optimum number of test cycles for each over-all degree of confidence regardless of the failure rate of the universe, $\bar{p}$, and in order to decrease the value of $\bar{p}$ without sacrificing test efficiency the sample size must be increased.

Figures 10, 11, and 12 show the application of the above procedure. Assume, for example, that originally six specimens were tested one at a time for 50 million cycles at each stress level on a loading-up basis in order to determine their endurance limit. Figure 11 shows that this test procedure has a machine test time of 350 × 10^6 cycles per stress level and a confidence of 80 per cent that the universe has a probability of failure of 26 per cent or less at the highest level at which no failures occur. Figures 11 and 12 show that the machine test time per level could be reduced to nearly half (machine test time of 184 × 10^6 cycles per stress level) for the same degree of confidence and $\bar{p}$ by testing 8 specimens 21 million cycles per stress level.

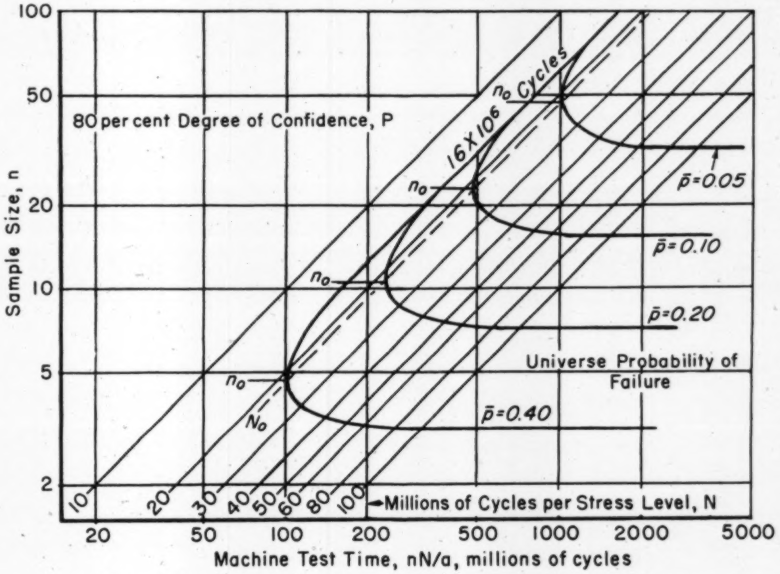

FIG. 11.—Effect of Sample Size and Test Cycles of Machine Test Time.

As can be easily seen, the above procedure uses the same basic concepts as presented in the paper but deals with the determination of the endurance limit or fatigue strength at a given number of cycles (P_N is made equal to 1.00 at the given number of cycles) instead of life at a given stress. Although the endurance limit could be obtained by extrapolating the S-N curve produced by the least-of-n method, it is believed that the above method will define better the endurance limit if the stress levels are fairly close together. The procedure above naturally has the same disadvantages as mentioned at the beginning of this discussion, if the testing is stopped as soon as a failure is obtained. If possible, it is usually advantageous to test most of the specimens to failure so that the mean strength and deviation can also be obtained.

MR. E. H. SCHUETTE (*author's closure*).—I would like to express my thanks to the discussors; I think they are doubtless all more versed in the field of statistics than I, and I consequently deeply appreciate their having given their careful consideration to the subject matter of my paper.

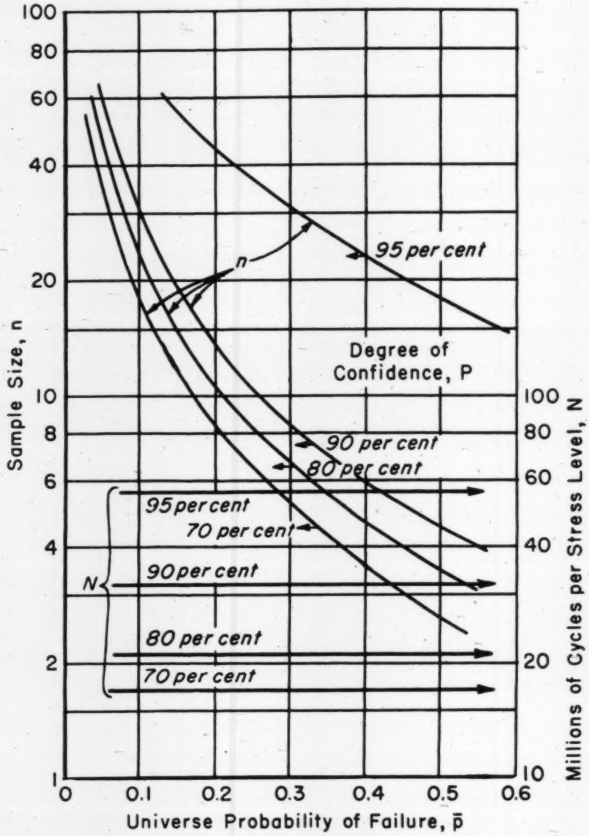

FIG. 12.—Sample Size and Test Cycles for Detecting Various Universe Probabilities of Failure for Least Machine Test Time.

Mr. Eaton has mentioned the tendency for component testing to show less scatter than is common to element testing. This is entirely logical; if we assume a component consists of n critical elements, then the testing of the component is tantamount to conducting a "least-of-n" test, and the scatter should decrease in accord with Fig. 7.

Whether or not four tests run in tandem, and carried successively to their individual failure times, would be more economical of time than would four separate tests stopped after the first failure, will depend on the amount of scatter with which one must contend. If the longest-lived has ten times the life of the shortest, then the tandem idea will require ten times this shortest lifetime, whereas the separate test will use machine time equivalent to four times the shortest life. If scatter is considerably less than this, the situation will tend to reverse itself.

I concur with Mr. McClintock's observation that the lowest of a sample of four is the lower 80 per cent confidence limit for any future single observation. I cannot agree, however, that the average fraction of the population lying above the broken line determined by the least-of-fours is 80 per cent. There is a very fine distinction here. In my opinion, the average fraction of the population lying above individual least-of-four points is indeed 80 per cent; but if a line is faired through such points, then, on the average, 84 per cent of the population will lie above the line. This difference derives, I think, from the skewness of the least-of-four distribution by comparison with the original distribution, whatever it may be.

The suggestion that design should be based on something better than 84 per cent confidence of survival is certainly well taken. In my own approach, I have left it up to the designer to choose factors of safety that will provide an adequate additional margin. If we assume that four tests per stress level is about all the average industrial laboratory can afford to run—and I think this is a realistic assumption—then the application of statistical procedures to determine a life for which there is 90 per cent confidence that 99.9 per cent of the population will exceed, will lead to wholly unrealistic results. To get so high a confidence from so few points, the mathematics will require, in effect, far greater factors of safety than are dictated by experience, and the designer will be faced with using stress values so low that he cannot even produce a feasible design.

Where it is practicable to use 20 or 30 specimens per stress level, it is possible to get realistic and usable values. Unfortunately, our own siutation will rarely, if ever, permit such an approach.

In our particular circumstances, using Krouse axial-load machines, we find specimen cost (including machining, polishing, mounting, and demounting) quite similar to that assumed by Mr. McClintock, and our machine and space costs are also of the assumed order of magnitude. We find it necessary, however, to utilize additional manpower during the early stages of a test, in order to make frequent adjustments compensating for creep and changes in the amount of plastic flow per cycle. The cost of this operation is about four dollars per test, irrespective of the number of specimens that might be mounted in the machine. The inclusion of this cost would therefore change considerably the final figures in Table IV.

There is, moreover, a common situation confronting a laboratory whereby it can find no space in which to install large numbers of new testing machines even if they were available. Under such circumstances, the only alternative is to develop ways of getting results faster from the machines on hand.

It is gratifying to note that Hamilton Standard have already made use of a multiple-specimen technique, using as many as six scale or full-size specimens. Considering the endurance limit, there is still some controversy as to whether such a limit is actually attained within any feasible number of cycles for magnesium alloys. Whenever the representation of an endurance limit can be justified, Dr. Cornell's contribution should offer a useful extension of statistical methods.

AN APPRAISAL OF THE PROT METHOD OF FATIGUE TESTING*

By H. T. Corten,[1] T. Dimoff,[1] and T. J. Dolan[1]

Synopsis

The Prot progressively increasing load method of fatigue testing was investigated by comparing the experimental results for three ferrous metals and an aluminum alloy with conventional fatigue data. Both notched and unnotched specimens were studied. The influence of the stress level at which the test was started and "coaxing" were investigated. Two procedures were employed in analyzing the data. The first method makes use of the results of conventional fatigue data (obtained with constant stress amplitude) to evaluate an experimental constant required to obtain the optimum value of the endurance limit from the Prot data. The second procedure employs the general method of least squares and statistical analysis to obtain the optimum value of the endurance limit and an estimate of the statistical variation from only the data obtained with progressively increasing loads. The Prot method of fatigue testing appears most promising for rapid estimation of the endurance limit of ferrous metals.

An important group of fatigue problems are concerned with load-resisting members subjected to a very large (infinite) number of repeated loads. In this group of problems, the determination of the endurance limit of the material by conventional laboratory methods (*S-N* curve) is often a long and expensive procedure. This is particularly true when information on the statistical variation of the endurance limit is desired. Also, after the endurance limit is established, the direct application of this information to the design of complex load-resisting members is somewhat uncertain due to such phenomena as the effect of state of stress, notch sensitivity, and size and shape effects. Consequently, testing of expensive complex assemblies is often necessary to determine endurance limit loads. Thus the desirability of a reliable short-time method for determining the endurance limit and estimating the statistical variation using only a relatively few specimens or complete assemblies has long been evident.

The Prot method (**1**)[2] of determining the endurance limit appears to incorporate many desirable features from the point of view of reducing the number of specimens required and the length of time for each test. In the Prot analysis, it was assumed that conventional fatigue data could be approximately represented by a hyperbola in the region of the endurance limit, that is $(S - S_e)N = K'$, where S_e is the endurance limit and K' is a constant. For load programs where the stress increases linearly with time or number of cycles, the relation between the *fracture stress* S_R and N was assumed to be another hyperbola with the same horizontal asymptote, S_e. If the increase in stress per cycle is denoted by α, Prot showed that, based on the above assumptions, a linear relation should exist between S_R and $\sqrt{\alpha}$, namely,

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* Presented at the Fifty-seventh Annual ing of the Society, June 13-18, 1954.

[1] Research Assistant Professor, Research Assistant, and Research Professor, respectively, Department of Theoretical and Applied Mechanics, University of Illinois, Urbana, Ill.

[2] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 893.

$$S_R = S_e + K\sqrt{\alpha} \qquad (1)$$

The endurance limit, S_e could be obtained from a diagram of S_R *versus* $\sqrt{\alpha}$ by extrapolation to $\alpha = 0$. At this point S_e could be read directly on the stress scale.

The advantage of this method lies in the fact that every specimen contributes to the determination of the endurance limit. Further, it offers a possibility of obtaining an estimate of the statistical variation of the endurance limit based on the statistical variation of a relatively few specimens by extrapolation to $\sqrt{\alpha} = 0$.

Henry (2) employing different assumptions, showed that Eq 1 could be obtained in more general form as

$$S_R = S_e + K\alpha^n \qquad (2)$$

where it was assumed that n is a material constant but may be different for different materials. Equation 2 is based on one of Weibull's (3) approximations to the conventional S-N diagram, namely,

$$\log N = \log k - m \log (S - S_e) \qquad (3)$$

and Miner's hypothesis (4) which assumes that the cumulative fatigue damage is identical with the summation of the cycle ratios of overstress applied. Henry's analysis gave the following approximate relation between n of Eq 2 and m of Eq 3:

$$n = \frac{1}{m + 1} \qquad (4)$$

In this relation m is the slope of the line obtained from a plot of log $(S-S_e)$ *versus* log N (Eq 3) employing conventional fatigue data.[3] For example, for 14B50 steel, a value of $m = 1.19$ was obtained from Fig. 1, and a value of $n = 0.456$ was computed from Eq 4. Using this value of n, it was found that the relation between S_R and α^n was approximately linear as will be noted later.

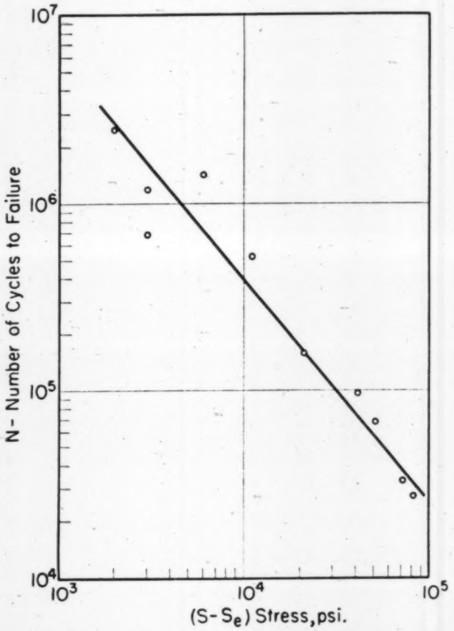

FIG. 1.—N *versus* $(S-S_e)$ Diagram for 14B50 Steel Unnotched Specimens (S_e = 59,000 psi). Slope of line is 1.193.

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[3] In order to plot the log $(S - S_e)$, an approximate value of S_e must be arbitrarily selected to give the straight line relationship indicated by Eq 3. This may be done by trial and error in the choice of S_e; however, in those instances where the complete S-N diagram was available, the endurance limit was used for S_e in analyzing the present data.

PURPOSE AND SCOPE

It is the purpose of this paper to appraise the usefulness and reliability of the Prot method of determining the endurance limit. The results are presented of an experimental investigation (**5,6**) of the Prot method applied to 75S-T6 aluminum alloy and three ferrous metals (ingot iron, SAE 2340 steel, and a boron steel). The steels cover a wide range of hardness and include notched and unnotched specimens. One of the assumptions inherent in the Prot analysis is that the relation between S_R and α^n is independent of the stress σ_0 (below the endurance limit) at which loading is initiated. It is assumed that cycles of stress below the endurance limit cause no damaging or strengthening effect in the material. Several different levels of stress were used at the start of the test to investigate the validity of this assumption. To study the possible effect of "coaxing" upon the endurance limit determined by the Prot method, two groups of specimens of ingot iron were prepared such that one group would be more susceptible to coaxing than the other (**7**). Table I lists all of the materials studied along with the type of specimen and starting stresses used.

TABLE I.—OUTLINE OF TEST PROGRAM.

Material	Type of Specimen	Starting Stress, psi
Aluminum Alloy 75S-T6	Unnotched	10 000
	Unnotched	20 000
Ingot Iron B	Unnotched	20 000
	Unnotched	10 000
Ingot Iron A	Unnotched	10 000
	Unnotched	30 000
SAE 2340 Steel	Unnotched	65 000
	Notched	30 000
	Notched	15 000
14B50 Steel	Unnotched	50 000
	Notched	35 000
	Notched	25 000

Since the exponent n in Eq 2 varies from one metal to another, appropriate values of n may be determined by the use of Eqs 3 and 4, but this requires the availability of conventional[4] fatigue data for the metals studied. To avoid the necessity of using conventional data, the general method of least squares for a nonlinear equation was applied to some of the test data obtained by the Prot method. This analysis allowed the determination of the optimum value of constants S_e, n, and K in Eq 2 from only the data obtained under progressively increasing loads. The value of n obtained by this method results in a linear relation between S_R and α^n that best fits the data.

The statistical variability of some of the data were analyzed to obtain an estimate of the standard deviation of the endurance limit as obtained by the Prot method.

MATERIALS AND EXPERIMENTAL METHOD

The materials were received as $\frac{5}{8}$ to $\frac{7}{8}$-in. diameter rolled bars. The blanks for the specimens were prepared from the bars in the as-received condition. For the unnotched specimens, a 0.30-in. minimum diameter was employed except for the SAE 2340 and 14B50 steels for which the minimum diameter was 0.25 in. The contour of the reduced section was turned with a 2-in. radius for all specimens. The SAE 2340 and 14B50 steel notched specimens had a minimum diameter of 0.25 in at the root of the semicircular notch whose radius was 0.050 in. Approximately one half of the ingot iron specimens, hereafter designated B, were quenched in water (Table II) to retain as much carbon and nitro-

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[4] The term "conventional" is used to indicate tests conducted at a constant stress amplitude.

TABLE II.—CHEMICAL COMPOSITION, HEAT TREATMENT, AND HARDNESS OF METALS TESTED.

Material	Chemical Composition		Time	Temperature, deg Fahr	Quench	Temper Time	Temper, deg Fahr	Hardness, Rockwell Scale	
								B	C
75S-T6 Aluminum Alloy	Zn Mg Cu Cr	5.6 2.5 1.6 0.3	As received (Rolled)					91.2	
Ingot Iron B	C Mn P S	0.012 0.017 0.005 0.025	1 hr	1400	Water			54	
Ingot Iron A	C Mn P S	0.012 0.017 0.005 0.025	As received (Hot rolled)						
SAE 2340 Steel	C Mn P S Si Ni	0.40 0.74 0.019 0.020 0.28 3.48	½ hr	1450	Oil	1 hr	1200	99	
14B50 Steel	C Mn P S Si B	0.52 0.84 0.011 0.030 0.27 0.0005	10 min	1550	Oil	1 hr	550		51

gen in solid solution as possible. It is known (7) that in this condition the iron is more susceptible to "coaxing" during the progress of the repeated load test than in the as-rolled condition which was designated A. The specimens of ingot iron B and boron steel 14B50 were machined before heat treating. These specimens were left approximately 0.002 in. larger in diameter than the finished specimen to allow for removal of light scale after the heat treatment. The SAE 2340 steel was machined after quenching and drawing. The ingot iron A and 75S-T6 aluminum were machined to size from the specimen blanks in the as-received condition. The specimens were polished using the standard procedure (8). After heat treatment, ingot iron B and boron steel 14B50 were given a light

TABLE III.—TENSILE PROPERTIES OF METALS TESTED.[a]

Material	Yield Strength, 0.2 per cent Offset, psi	Tensile Strength, psi	Elongation, per cent in 2 in.	Reduction of Area, per cent
75S-T6 Aluminum Alloy	73 100	83 000	16	31.6
Ingot Iron B	33 000	55 125	21.5	66.5
Ingot Iron A	54 000	62 900	18	65.6
SAE 2340 Steel	92 100	112 900	26.5	64.8
14B50 Steel	242 000	271 500	9.25	45.8

[a] All values represent the average of at least two tests. Specimens were 0.505 in. diam and gage length was 2 in.

polish with 00 emery polishing paper. The chemical composition, heat treatment, and resulting hardness of the four metals are given in Table II. The standard tensile properties of all materials are listed in Table III.

TABLE IV.—COMPARISON OF ENDURANCE LIMITS OBTAINED BY THE CONVENTIONAL METHOD AND THE PROT METHOD.

Material	Type of Specimen	Endurance Limit by Conventional Test, psi	Starting Stress, psi	Exponent n	Endurance Limit by Prot Method, psi
75S-T6 Aluminum Alloy	Unnotch	25 000[a]	20 000	0.5	...
			20 000	0.178	20 500
			10 000	0.5	...
			10 000	0.178	17 000
Ingot Iron B	Unnotch	23 000	20 000	0.5	28 100
			20 000	0.371	26 800
			10 000	0.5	28 800
			10 000	0.371	26 800
Ingot Iron A	Unnotch	34 000	30 000	0.5	38 500
			30 000	0.371	36 200
			10 000	0.5	36 700
			10 000	0.371	35 400
SAE 2340 Steel	Unnotch	69 000	65 000	0.5	71 700
			65 000	0.418	69 500
	Notch	38 000	30 000	0.5	42 500
			30 000	0.4	40 700
			30 000	0.318	38 800
			15 000	0.5	39 200
			15 000	0.4	38 300
			15 000	0.318	36 900
14B50 Steel	Unnotch	61 000	50 000	0.5	60 000
			50 000	0.456	61 100
			50 000	0.717	68 000
	Notch	39 000	35 000	0.50	37 500
			35 000	0.55	38 400
			25 000	0.50	37 000
			25 000	0.55	38 300

[a] Fatigue strength at 10^8 cycles.

The progressively increasing load experiments were conducted in rotating-cantilever-beam machines (5) by adding water to a load container. The uniform flow of water was controlled by employing a constant head standpipe which supplied water through a needle control valve to the load container.

In testing boron steel 14B50, the machine was operated at approximately 7200 rpm, and all specimens developed fatigue fractures. The speed of the machines was reduced to approximately 3600 rpm for SAE 2340 steel, ingot iron, and 75S-T6 aluminum. The slower speed was employed in an attempt to reduce further the severe shock to the machine caused by the plastic bending failure which occurred for some of the specimens. Bending occurred in a number of ingot iron specimens for which the value of α was 0.04 psi per cycle or greater. In those cases where α exceeded 0.04 psi per cycle, the stress in the specimen had reached or exceeded the yield strength of the metal when plastic bending occurred. The loading rate α was computed from the initial and final load on the specimen and the number of cycles to failure.

75S-T6 Aluminum:

Typical results of the progressively increasing load experiments are shown in Fig. 2 for one of the two starting stresses used, $\sigma_0 = 20{,}000$ psi. The data have been plotted employing two values of the exponent n. When $n = 0.5$ is used, the relation between S_R and α^n is sharply curved in the range of small values of α^n, and linear extrapolation to $\alpha^n = 0$ is not feasible. A value of the exponent $n = 0.178$ was obtained from Eq 4 when the value of S_e was adjusted ($S_e = 19{,}000$ psi) to give a linear relation between log N and log $(S - S_e)$.

With this value of n, the fracture stresses were approximately linearly related to α^n as is shown in Fig. 2. This same value of n also gave a linear relation for the experimental data when a starting stress of $\sigma_0 = 10{,}000$ psi was employed.

The endurance limits determined by

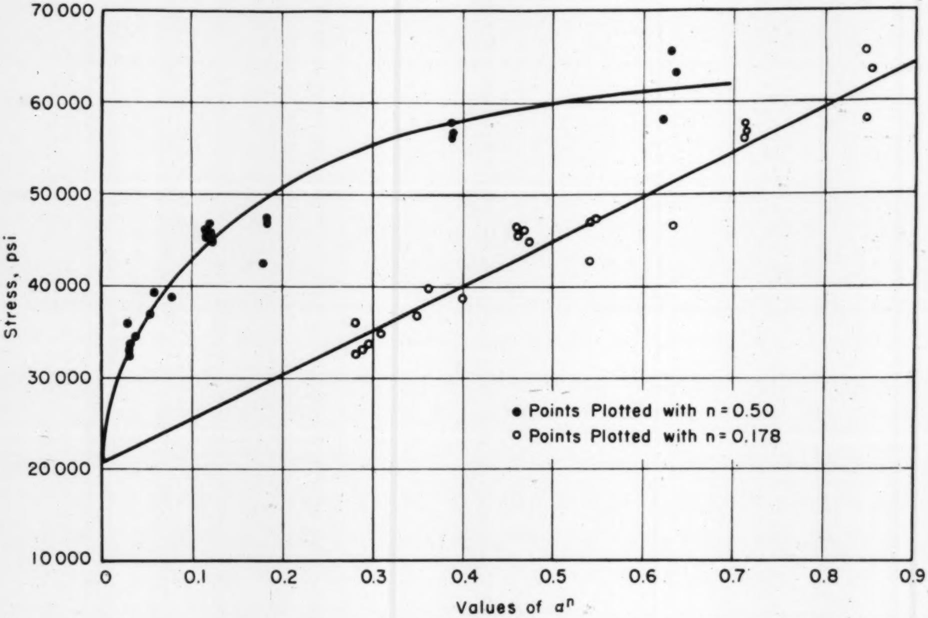

FIG. 2.—Fatigue Fracture Stresses Under Progressively Increasing Loading. 75S-T6 aluminum alloy unnotched specimens ($\sigma_0 = 20{,}000$ psi).

EXPERIMENTAL RESULTS AND DISCUSSION

In the following discussion, the results for each material are considered separately. All of the data have been analyzed using the value of the exponent $n = 0.5$ as proposed by Prot, and also by using a value of n determined from conventional fatigue data by Eqs 3 and 4. Some of the data for 14B50 steel have been analyzed to determine values of n, K, and S_e by the general method of least squares and statistical theory. A summary of the results for the four materials are presented in Table IV.

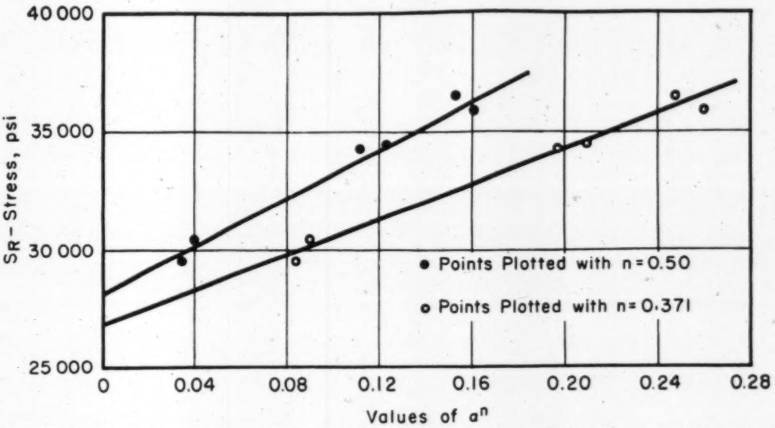

FIG. 3.—Fatigue Fracture Stresses Under Progressively Increasing Loading. Ingot iron B unnotched specimens (σ_0 = 20,000 psi).

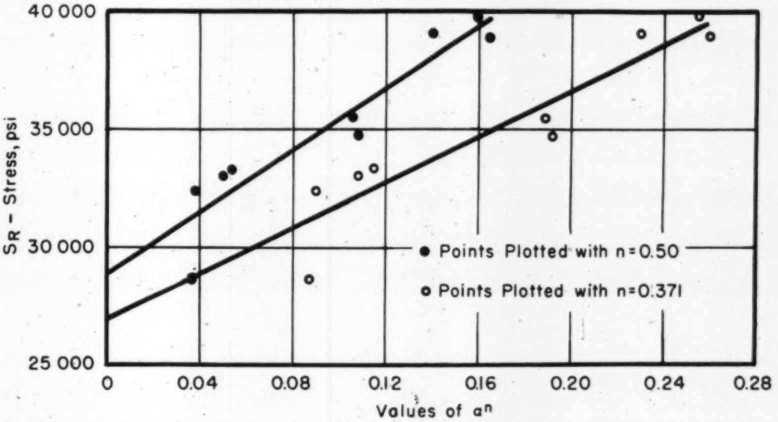

FIG. 4.—Fatigue Fracture Stresses Under Progressively Increasing Loading. Ingot iron B unnotched specimens (σ_0 = 10,000 psi).

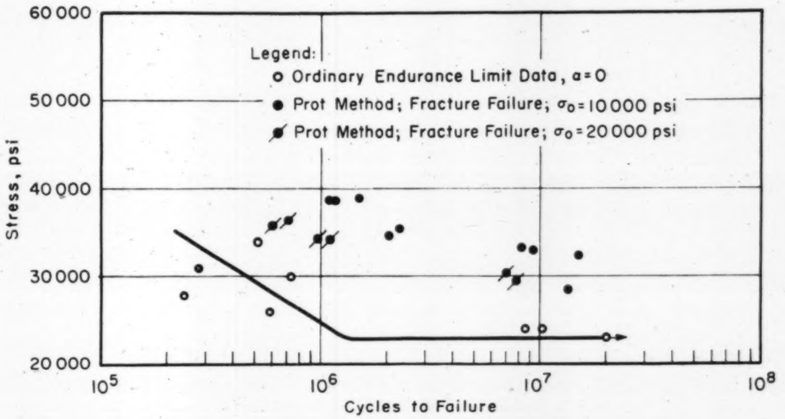

FIG. 5.—*S-N* Curve for Ingot Iron B Unnotched Specimens.

the progressively increasing load method[5] (n = 0.178) were lower than the fatigue strength of the 75S-T6 aluminum at 10^8 cycles. This is not surprising in view of the fact that the endurance limit determined by this method implies an infinite life (or an asymptote to the lower portion of the conventional *S-N* curve).

If the results for 75S-T6 aluminum can be considered typical of other non-ferrous metals, it is obvious that use of the exponent $n = 0.5$ is not satisfactory for this class of materials. The modified analysis proposed by Henry (2) depends upon the proper choice of a value for the exponent n for a non-ferrous metal, the accuracy of fit of Weibull's empirical relation (Eq 3) over a wide range of N, and the reliability of Miner's hypothesis (4). Based on the uncertainties of the last two factors (and the rather arbitrary preliminary choice that must be made for S_e in plotting the log N *versus* log $(S-S_e)$ relation), it appears that there exists a range of values of endurance limit that may be obtained by the Prot method. Consequently the usefulness of the Prot method may be rather limited for non-ferrous metals unless it is found that a single value of n may be used for all alloys of a given type (such as aluminum alloys).

Ingot Iron:

The progressively increasing load experiments for the two groups of ingot iron specimens (A and B) each employed two starting stresses, σ_0, as listed in Table I. Two values of the exponent n were used, $n = 0.5$ and $n = 0.371$. The value of the exponent, $n = 0.371$ was determined independently for each group of specimens A and B from diagrams of log N *versus* log $(S - S_e)$. Typical results of the experiments, for ingot iron B are plotted in Figs. 3 and 4. Both values of n appear to give a linear relation between S_R and α^n for the small range of values of α^n covered by these data. The same observation was made for iron A. The data obtained by the conventional method of fatigue testing for iron B together with the fracture stresses under progressively increasing load are shown on the *S-N* diagram in Fig. 5.

A comparison of the values of the endurance limits (see Table IV) shows that for both irons A and B the Prot method endurance limits are higher than those determined by the conventional method. The use of $n = 0.371$ gives somewhat better agreement than $n = 0.5$. The absolute differences are not large; however, by the Prot method, the endurance limits are from 4 to 13 per cent high for iron A, and from 16 to 25 per cent high for iron B. These differences should be considered approximate because of the lack of knowledge of the statistical variations of the data; however, for iron B the difference appears large enough to establish a trend.

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[5] In the diagrams of S_R *versus* α^n, the intercept with the S axis represents the endurance limit, S_e, of the material. In determining the equation of the straight line for best fit, the method of least squares was used (9). The equation of this straight line is

$$S_R = S_e + K\alpha^n \qquad (2)$$

The constants S_e and K are determined as follows:

$$S_e = \frac{\Sigma(\alpha^n)^2 \cdot \Sigma S_R - \Sigma\alpha^n \cdot \Sigma\alpha^n \cdot S_R}{M\Sigma(\alpha^n)^2 - (\Sigma\alpha^n)^2}$$

$$K = \frac{M\Sigma\alpha^n\, S_R - \Sigma\alpha^n \cdot \Sigma S_R}{M\Sigma(\alpha^n)^2 - (\Sigma\alpha^n)^2}$$

where M is the total number of specimens. A similar procedure was used to determine the exponent m from log N *versus* log $(S - S_e)$ diagrams.

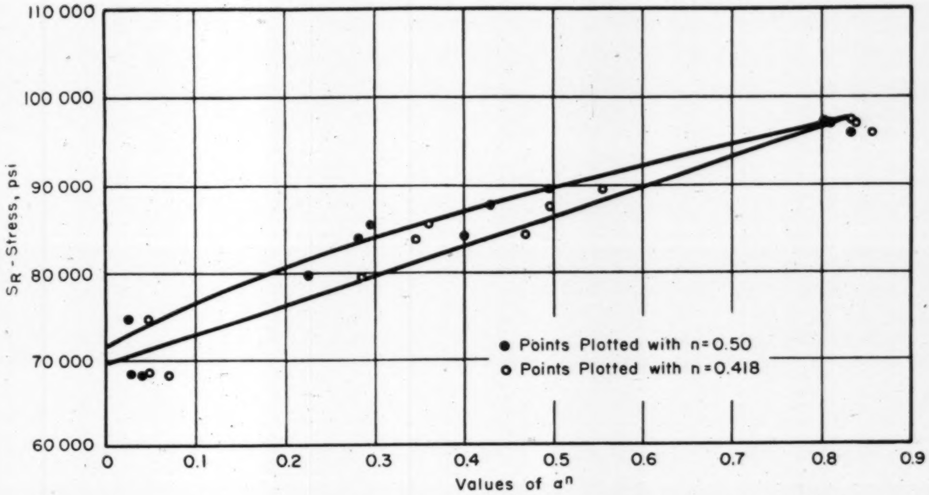

FIG. 6.—Fatigue Fracture Stresses Under Progressively Increasing Loading. SAE 2340 steel unnotched specimens (σ_0 = 65,000 psi).

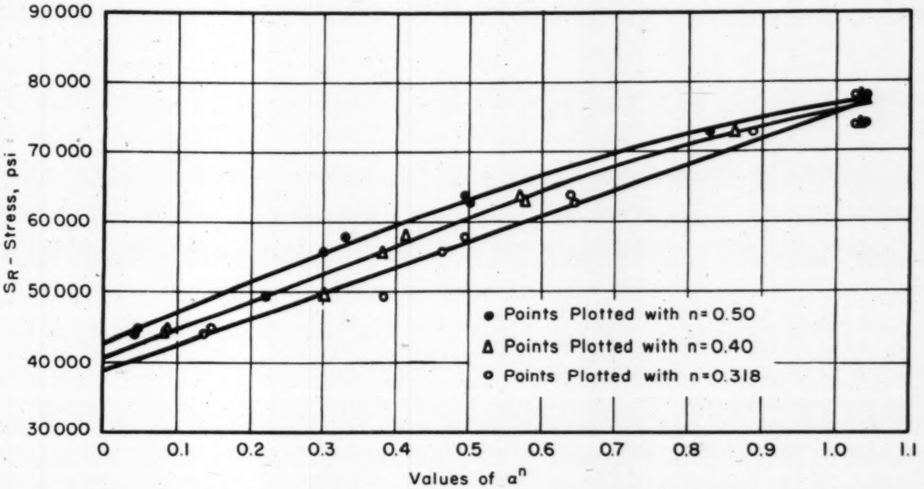

FIG. 7.—Fatigue Fracture Stresses Under Progressively Increasing Loading. SAE 2340 steel notched specimens (σ_0 = 30,000 psi).

The question of the effect of "coaxing" was raised previously (5) and ingot iron B was purposely heat treated to a condition that is susceptible to "coaxing" (7). It is suspected that the "coaxing" phenomenon was largely responsible for the higher values of S_e determined by the Prot method, particularly for iron B. In support of this, it should be noted that for iron B a lower starting stress resulted in the same or higher value of S_e (see Fig. 5 also). This is the reverse of the effect noted for different starting stresses for 75S-T6 aluminum or ingot iron A (see Table IV) and is consistent with the concept that the "coaxing" phenomena was largely responsible for the increased endurance limit as determined by the Prot method. Thus it appears that for metals that are susceptible to "coaxing" (certain ferrous alloys (7)), the Prot method of determining the endurance limit may lead to estimates of the endurance limit that are too high.

The Prot method of determining the endurance limit was limited to the lower loading rates (low values of α) due to the fact that at higher values of α the specimens failed by plastic bending instead of progressive fracture. Many of the specimens also failed by plastic bending after developing a small crack. However, it is thought that the presence of the crack contributed to excessive vibration of the specimen late in the test; therefore, these failures are reported as resulting from progressive fracture.

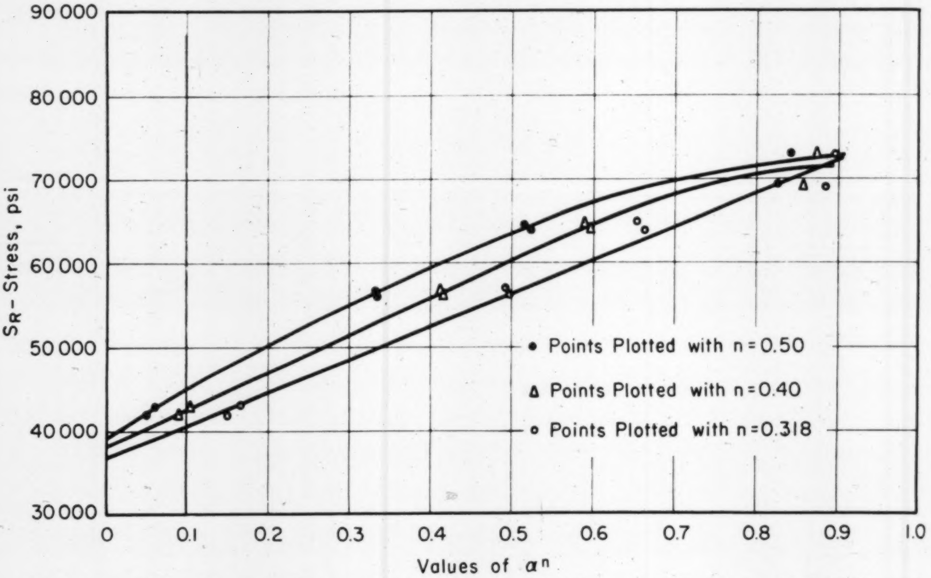

FIG. 8.—Fatigue Fracture Stresses Under Progressively Increasing Loading. SAE 2340 steel notched specimens (σ_0 = 15,000 psi).

It is interesting to note from Fig. 5 that when very low loading rates must be employed the progressive load and conventional methods require comparable numbers of cycles and time to fracture.

SAE 2340 Steel:

The experimental results for the Prot method are presented in Fig. 6 for unnotched specimens tested using a starting stress, σ_0, of 65,000 psi and in Figs. 7 and 8 for notched specimens using starting stresses, σ_0, of 30,000 and 15,000 psi respectively. Two values of the exponent n have been used in plotting the data in Fig. 6 and three values in Figs. 7 and 8. In Figs. 6 to 8 the data are plotted for $n = 0.5$; however, it is obvious that the relation between the fracture stress S_R and α^n is not linear. To obtain an estimate of the value of n that would give a linear relation, diagrams of which Fig. 9 is a sample were plotted to include the present conventional fatigue data plus more extensive data available from a previous investigation (10) of the same material. The values of n obtained by applying the method of least squares to only the data from reference (10) gives $n = 0.418$ for unnotched specimens and $n = 0.40$ for notched specimens. Using the respective values of n, the data were replotted as shown in Figs. 6 to 8 resulting in a more nearly linear relation between S_R and α^n.

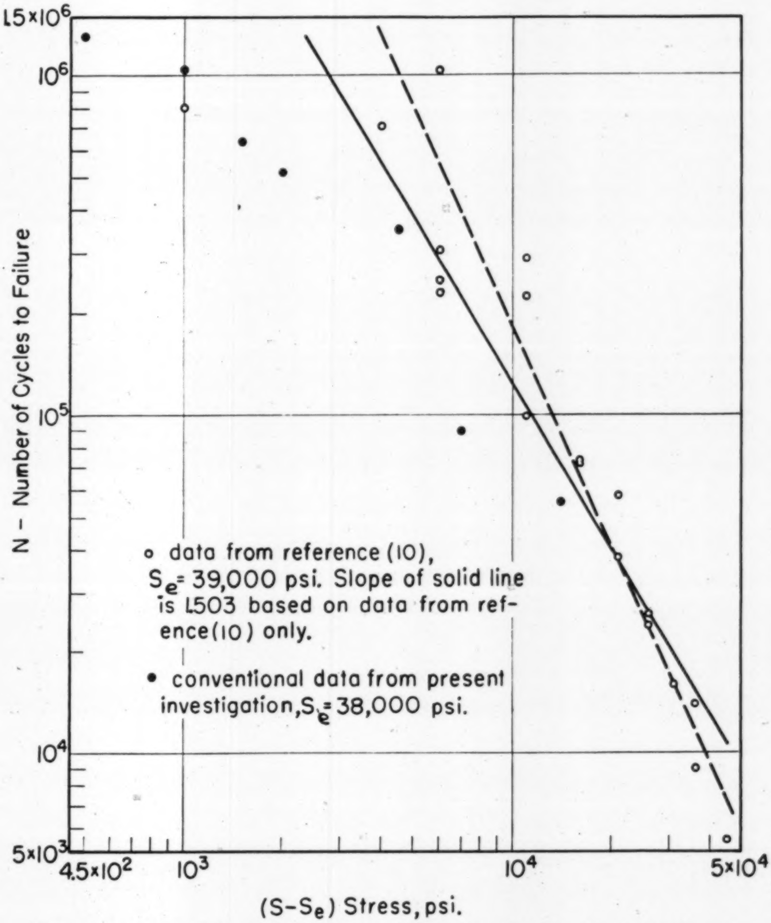

FIG. 9.—*N versus* $(S-S_e)$ Diagram for SAE 2340 Steel Notched Specimens.

In Fig. 9 the line for notched specimens obtained by the method of least squares appears to be considerably influenced by the wide scatter of points in the range between $N = 5 \times 10^5$ to 10^6 cycles. To study further the use of diagrams such as Fig. 9, an additional dashed line was drawn by eye that appears to represent better the data in the range below 3×10^5 cycles. From the slope of this line, a value of $n = 0.318$ was obtained. The Prot data in Figs. 7 and 8 were also replotted using this value of n and appear to give the most nearly linear relation between S_R and α^n for this exponent.

The values of S_e obtained by the Prot method (see Table IV) for unnotched specimens agree very closely with the results of the conventional method. The exponent, $n = 0.418$, appears to give slightly better agreement than $n = 0.5$. For notched specimens, the values of S_e obtained by the Prot and conventional method appear to agree best when a value of $n = 0.318$ is used to plot the Prot data. The value of $n = 0.40$ gives good agreement for a starting stress σ_0 of 15,000 psi, but for $\sigma_0 = 30{,}000$ psi the difference is larger.

These results should be viewed in the light of the statistical variation inherent in the determination of the endurance limit. The endurance limit by the conventional method was bracketed between one or two specimens that did not fracture at a given stress level (see Fig. 10) and two or three specimens that did fracture at stress levels from 500 to 2000 psi higher. The information that is available (11) on the variability of the endurance limit of other materials indicates that the standard deviation may be several thousand pounds per square inch. Thus when the results of the Prot and conventional methods differ by only several thousand pounds per square inch, it does not appear possible to differentiate accurately between the results obtained by using different values of n.

From the results of the notched and unnotched specimens, it is impossible to decide whether or not n is a material constant. Because of the variability of the endurance limit and the relative insensitivity of S_e to changes in n, it is suggested that for practical purposes the assumption of a constant value of n for a given material is sufficiently reliable.

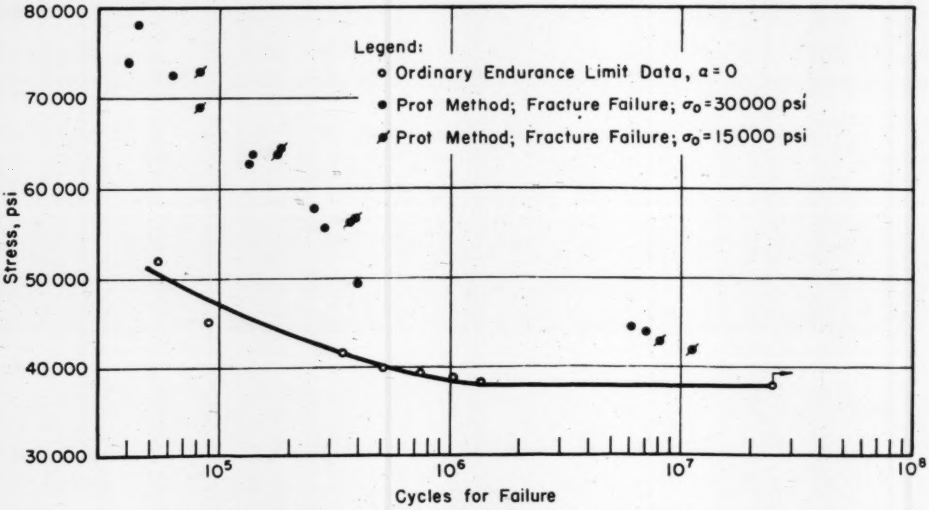

FIG. 10.—*S-N* Curve for SAE 2340 Steel Notched Specimens.

The variation of the value of S_e obtained with the Prot method due to different starting stresses for notched specimens is of the same magnitude as was obtained with unnotched specimens. This difference is not large, but it does represent a deviation from one of the basic assumptions of the Prot theory. From the practical standpoint, this small difference may not be significant.

From Fig. 9 it appears that there may be some question about the proper interpretation of these diagrams. For small values of N, approximately 100,000 cycles and less, a second line of different

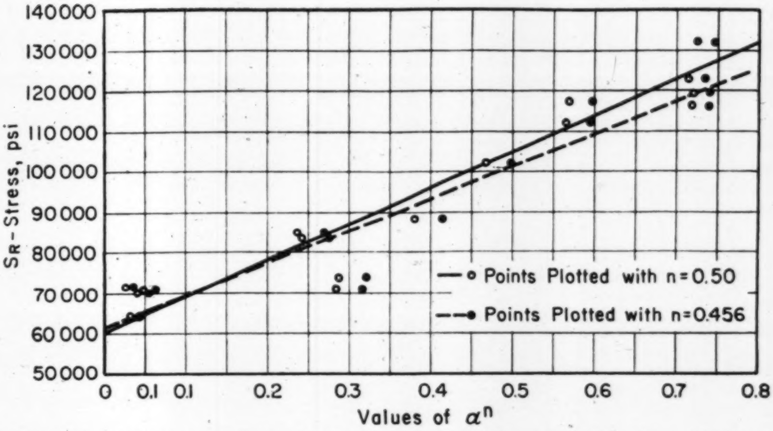

FIG. 11.—Fatigue Fracture Stresses Under Progressively Increasing Loading. 14B50 unnotched specimens (σ_0 = 50,000 psi).

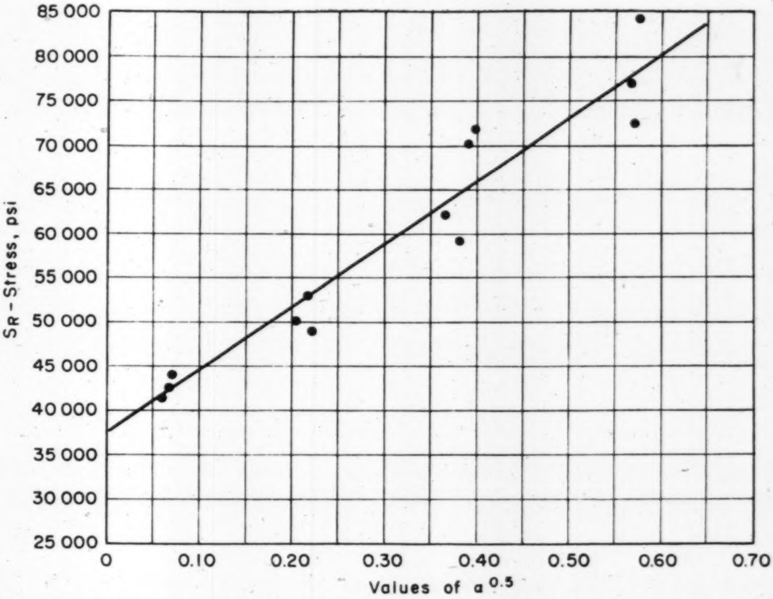

FIG. 12.—Fatigue Fracture Stresses Under Progressively Increasing Loading. 14B50 notched specimens (σ_0 = 35,000 psi).

slope often appears to fit these data better (2, 3). For larger values of N, the scatter is often large and the trend of the data is difficult to determine. Thus this method of estimating n may be misleading when conventional data from only a few specimens are available. In terms of the modified Prot theory, this may also mean that it would be desirable to use a variable value of n in plotting the S_R *versus* α^n diagrams. However, considering the insensitivity of S_e to changes of n and the empirical assumptions upon which the modified Prot theory is based, it appears doubtful that such a refinement is justified.

Boron Steel 14B50:

The experimental results of the tests under progressively increasing load are presented in Fig. 11 for unnotched specimens using starting stress of 50,000 psi and in Figs. 12 and 13 for notched specimens using starting stresses of 35,000 and 25,000 psi respectively. In Fig. 11 for unnotched specimens the data are plotted using $n = 0.5$ and $n = 0.456$. The value of n of 0.456 was obtained from Fig. 1, a diagram of log N *versus* log $(S - S_e)$, using conventional fatigue data for unnotched specimens and Eq 4. As sufficient conventional data were not available, a value of n for notched specimens was not determined by this procedure.[6]

For the unnotched specimens, the values of the endurance limit (see Table IV) using either value of n are in close agreement with the value obtained by the conventional method. The conventional data are presented in an S-N diagram, Fig. 14, for unnotched specimens. The endurance limits obtained by the Prot method for notched specimens using $n = 0.5$ were slightly lower than the value obtained by con-

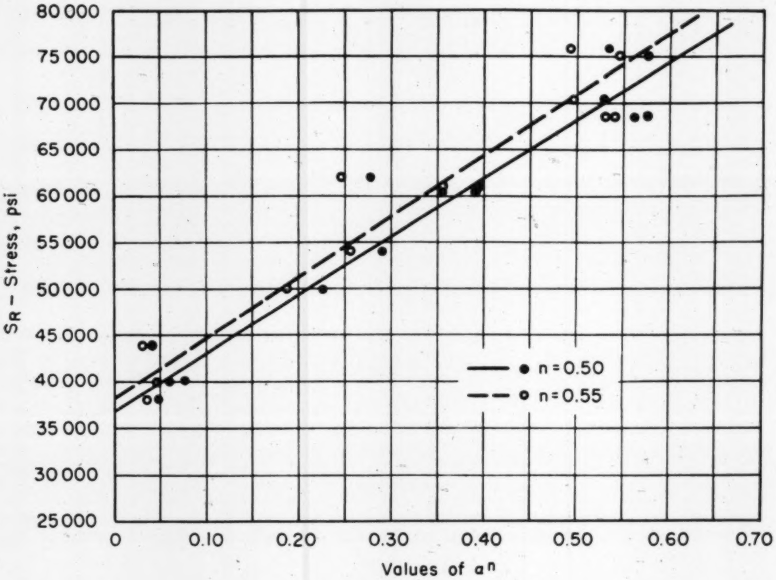

FIG. 13.—Fatigue Fracture Stresses Under Progressively Increasing Loading. 14B50 notched specimens (σ_0 = 25,000 psi).

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[6] In the next section another method of obtaining a value of n is discussed. The value of $n = 0.55$ was obtained for notched specimens by this method and the results will be discussed in the next section.

ventional methods for both starting stresses. However considering the statistical variability of the endurance limit (11), it is not possible to determine accurately whether the difference between the Prot and conventional results is really significant.

The results for boron steel indicate that, like the SAE 2340 steel, the Prot method appears to be as reliable for notched as for unnotched specimens. The implication is that the Prot method is probably as applicable for testing odd-shaped complex machine members as for laboratory specimens.

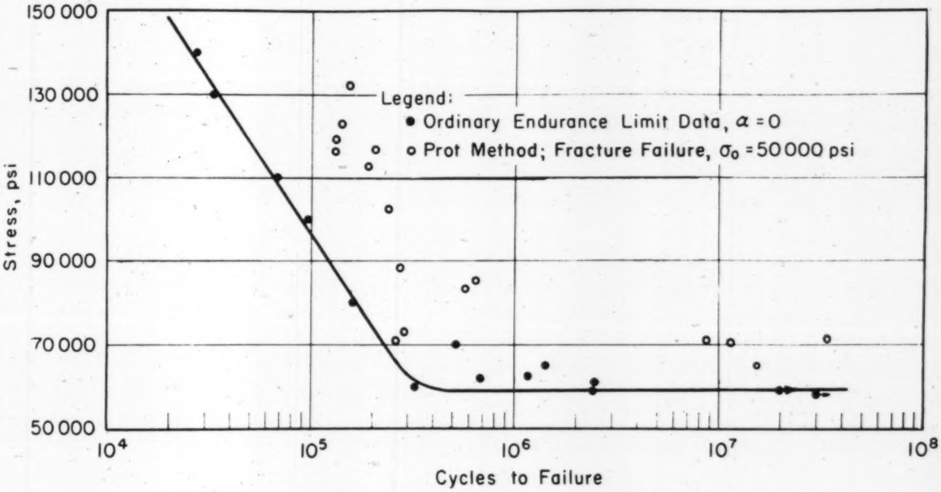

FIG. 14.—*S-N* Curve for 14B50 Steel Unnotched Specimens.

For the notched specimens, the two starting stresses resulted in slightly different values of S_e; however, for the boron steel the difference is so slight that it must be considered insignificant. It is interesting to note, by comparison of Figs. 12 and 13, that different starting stresses result in larger differences at higher values of α but the lines representing the data tend to converge as α approaches zero. This tendency was found to exist for all materials; however, from a practical standpoint in determination of the endurance limit, it has no apparent significance.

From Tables II and III it will be noted that the boron steel is a very hard, high static strength material. However the fatigue strength does not reflect this tendency. Photomicrographs of the cross-section of the specimen at the surface showed that the surface layer was slightly decarburized. Presumably fatigue cracks develop in the decarburized surface layer and then spread to the higher strength interior with the aid of the stress concentration at the root of the sharp crack. This softer surface layer may also account for the relatively low notch sensitivity exhibited by the notched specimens of boron steel.

INTERPRETATION OF PROT DATA BY GENERAL METHOD OF LEAST SQUARES

In order to avoid the necessity of employing conventional data to obtain a suitable value of n to be used in plotting the Prot data, it is desirable to consider the methods that require only the Prot data for a complete analysis. One such method is the "General Method of Least Squares Applied to a Nonlinear Formula" (12). This method utilizes estimates of the constants S_e, K, and n in Eq 2 to obtain corrections to these constants by the ordinary method of least squares. The corrections are obtained from an approximate formula which becomes more exact the smaller the values of the corrections. The successive application of this procedure results in corrections which rapidly become small compared to the constants S_e, K, and n; thus the optimum values may be obtained employing only the Prot data.

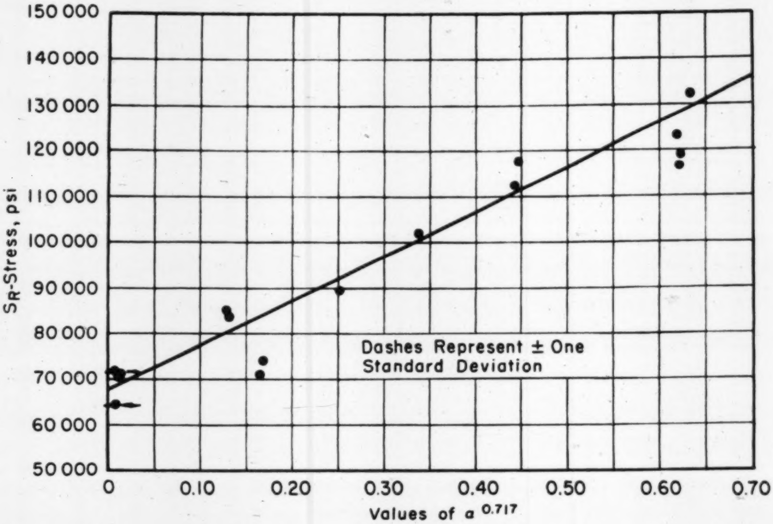

FIG. 15.—Fatigue Fracture Stresses Under Progressively Increasing Loading. 14B50 unnotched specimens (σ_0 = 50,000 psi).

This method was applied to the Prot data for steel 14B50. The data in Fig. 11 for unnotched specimens and in Fig. 12 for notched specimens using a starting stress of 35,000 psi were chosen for this study. The values of n obtained by this method were 0.717 and 0.55 for unnotched and notched specimens respectively. Diagrams of S_R *versus* α^n using these values of n are shown in Figs. 15 and 16. The solid straight lines represent the optimum fit of a straight line to the test data. The value of S_e obtained for the unnotched specimens (see Table IV) is somewhat higher than the value obtained by the conventional method. It appears that the two unusually low points ($\alpha^n = 0.17$ in Fig. 15) influenced the value of n and S_e considerably in this case. The value of S_e computed for the notched specimens by this method is in excellent agreement with the value obtained by the conventional method. This procedure was not applied to the notched specimens tested using a starting stress of 25,000 psi. However the value of $n = 0.55$ (obtained from notched specimens tested with a starting stress of 35,000 psi) was also used to plot the data for notched specimens that were started with $\sigma_0 =$ 25,000 psi. The results are shown in Fig. 13 and the value of S_e is listed in Table IV. The values of S_e for both sets of notched boron steel specimens appear to be in closer agreement with the results of the conventional method when plotted using $n = 0.55$ than for $n = 0.5$.

The advantage of this method is that

only the data obtained with progressively increasing loads are required; however, the method inherently assumes that the relation between S_R and α^n is linear and that the distribution of the observed values of S_R about its mean is normal. As the assumptions made in the theory to arrive at a linear relation are empirical and not always borne out by experimental data (13), the usefulness of this procedure is restricted to those cases where S_R and α^n can reasonably be assumed to be linearly related. From all of the data available (1, 14, 15, 16) it appears that for small values of α, the assumption of a linear relation is reasonable. The assumption of a normal distribution of S_R about the mean also appears reasonable, at least as a first approximation (14).

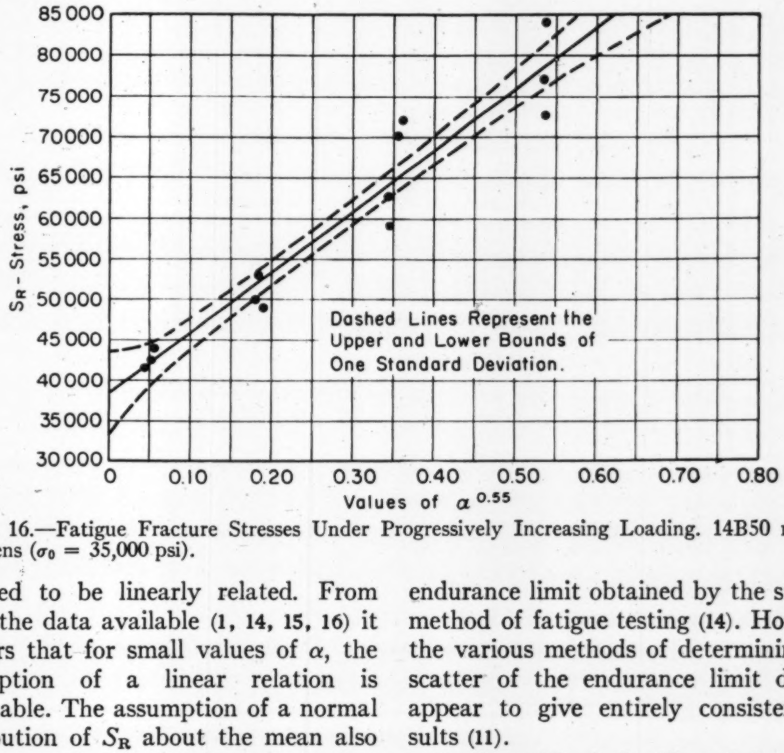

FIG. 16.—Fatigue Fracture Stresses Under Progressively Increasing Loading. 14B50 notched specimens (σ_0 = 35,000 psi).

Determination of the Standard Deviation from Prot Data:

The statistical variability of the results of fatigue experiments makes knowledge of the expected variation of the endurance limit as important as knowledge of the mean value.[7] The Prot method allows measurement of the fracture stress, S_R, which is related to the endurance limit by Eq 2. Consequently the variation of the endurance limit is obtainable only indirectly from the variability of S_R. Prot originally suggested that the variation of S_R at different values of α may be constant and equal to the variation of S_e. There are some data to indicate that the variation of S_R may be constant and approximately equal to that for the endurance limit obtained by the step-up method of fatigue testing (14). However, the various methods of determining the scatter of the endurance limit do not appear to give entirely consistent results (11).

In view of the lack of knowledge of the relation between the variation of S_e and S_R, the standard deviation of S_R at

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[7] By definition, the endurance limit stress is that stress at or below which fatigue fracture does not occur. However, when considering the scatter of experimental data, it is convenient to deal with the mean value and the standard deviation about the mean. The term "endurance limit" is used in this report to indicate the mean value.

$\alpha = 0$ has been determined purely on the basis of statistics, assuming only that the two distributions are normal. The theory is an extension of the theory for obtaining the optimum values of S_e, K, and n by the method of least squares. The standard deviation of values of S_R is very closely related to the sum of the squares of the difference between the observed and estimated (optimum) values of S_R (17).

This method applied to the data for boron steel gave results that are presented in Figs. 15 and 16. In Fig. 15 the short dashes on the stress axis represent ± one standard deviation of S_e, that is for S_R at $\alpha = 0$. In Fig. 16 the dashed lines on either side of the solid line represent upper and lower bounds for one standard deviation from the optimum curve over a range of values of α. The values obtained for the magnitude of the standard deviation of S_e are reasonable (11, 14); however, it should be noted that the standard deviation increases markedly (diverging dashed lines in Fig. 16) outside of the range covered by the experimental data. It appears that the value selected for the smallest α employed in testing has a pronounced influence on the value of standard deviation obtained for $\alpha = 0$. That is, the standard deviation of S_e will be increased if only larger values of α are used in the experiment. Thus the value of standard deviation obtained by this method depends upon the experimental design (choice of α) and may be larger than the true value. For the purpose of estimating the scatter, this result may be useful as it leads to an estimate that is on the safe side.

CONCLUSIONS

1. The Prot method of fatigue testing gives information about the endurance limit of the metal only. Consequently the method appears to be more promising for ferrous metals with a well-defined endurance limit than for non-ferrous metals where the fatigue strength at a given life must be considered.

2. The modified Prot theory in which the exponent n (in Eq 2) may be different for different metals, produces better agreement with conventional fatigue data than does the original Prot interpretation based on $n = 0.5$.

3. The use of progressively increasing loads to obtain a reliable estimate of the endurance limit depends upon a knowledge of the appropriate value of n; its value may be approximately constant for a given material regardless of the shape of the specimen. Approximate values of n may be obtained from previous conventional fatigue data for similar metal using log N *versus* log $(S - S_e)$ diagrams and Eq 4.

4. For ferrous metals the exponent n was found to be reasonably close to 0.5 $(0.31 < n < 0.71)$ in all cases. For rapid estimation of the endurance limit, $n = 0.5$ appears to give satisfactory results if a smooth curve is drawn through the data. However, such a procedure was unsatisfactory for 75S-T6 aluminum alloy.

5. Various levels of starting stresses that are below the endurance limit lead to approximately the same value for the endurance limit. In general, lower starting stresses resulted in a slightly lower value of S_e. This would indicate that an influence of repeated loading at stress levels below the endurance limit was present; however, the variations were relatively small except when the metal was susceptible to "coaxing."

6. For ferrous metals that are susceptible to "coaxing," the Prot procedure affords an opportunity for "coaxing" to occur which appreciably raises the estimated value of S_e as compared to the value obtained by conventional method.

7. Endurance limits determined by progressive loading of notched specimens were in close agreement with the values obtained by the conventional (constant stress amplitude) method. This indicates that the Prot method may be applicable to members of any shape including full-sized structures. However, it is doubtful that the Prot method will give reliable results in instances where environmental conditions such as corrosion, erosion, or elevated temperatures contribute to the initiation of fatigue cracks. The short-time nature of the test precludes the complete development of detrimental conditions that are functions of time.

8. The method of least squares has been applied to some of the data to estimate the optimum values of the constants, S_e, K, and n in Eq 2, and the standard deviation of the fracture stress extrapolated to $\alpha = 0$ (and hence of S_e) employing only Prot data. This method gives reasonable estimates of the constants and variability of S_e in the cases investigated. However, due to lack of comparable data for standard deviation obtained by other methods, the reliability of these results is not known. The estimate of variability depends upon the smallest value of α used in the experiments and may overestimate the statistical variation in endurance limit if this value of α is reasonably large.

Acknowledgment:

This investigation has been conducted in the research laboratories of the Department of Theoretical and Applied Mechanics as part of the work of the Engineering Experiment Station, University of Illinois, in cooperation with the Office of Naval Research, U. S. Navy, under Contract N6-ori-071(04). This paper summarizes the results of the work contained in Technical Reports Nos. 34 and 35. The contributions made to this research by A. P. Boresi (5) and Masaki Sugi (6) and the assistance of G. L. Lovestrand in preparing the illustrations are gratefully acknowledged.

References

(1) E. Marcel Prot, "Fatigue Testing Under Progressive Loading; A New Technique for Testing Materials," *Revue de Metallurgie*, Vol. XLV, No. 12, p. 481 (1948). English translation by E. J. Ward, WADC Technical Report 52-148, Wright Air Development Center, Sept., 1952.

(2) D. L. Henry, "Prediction of Endurance Limits Using Linearly Increasing Loads," Unpublished Report, March 10, 1951.

(3) W. Weibull, "Statistical Representation of Fatigue Failures in Solids," Kungl Tekn. Hogsk. Handlingan No. 27, 1949.

(4) M. A. Miner, "Cumulative Damage in Fatigue," *Transactions*, Am. Soc. Mechanical Engrs., Vol. 67, pp. A-159-164 (1945).

(5) A. P. Boresi and T. J. Dolan, "An Appraisal of the Prot Method of Fatigue Testing, Part I," Tech. Report 34, ONR Project NR-031-005, Theoretical and Applied Mechanics Dept., University of Illinois, January, 1953.

(6) H. T. Corten, Todor Dimoff, T. J. Dolan, and Masaki Sugi, "An Appraisal of the Prot Method of Fatigue Testing, Part II," Tech. Report 35, ONR Project NR-031-005, Theoretical and Applied Mechanics Dept., University of Illinois, June, 1953.

(7) G. M. Sinclair, "An Investigation of the Coaxing Effect in Fatigue of Metals," Tech. Report No. 28, ONR Project NR-031-005, University of Illinois, March, 1952; also *Proceedings*, Am. Soc. Testing Mats., Vol. 52, p. 743 (1952).

(8) Fatigue Manual, Am. Soc. Testing Mats., p. 35 (1949). (Issued as separate publication *ASTM STP No. 91*).

(9) A. G. Worthing and J. Geffner, "Treatment of Experimental Data," John Wiley and Sons, Inc., New York, N. Y., pp. 239-243 (1943).

(10) T. J. Dolan, F. E. Richart, Jr., and C. E. Work. "The Influence of Fluctuations in Stress Amplitude on the Fatigue of Metals; Part I," Seventh Progress Report, and

Part II, Ninth Progress Report, ONR, Project NR-031-005, University of Illinois (1948). Also *Proceedings*, Am. Soc. Testing Mats., Vol. 49, p. 646 (1949).

(11) Symposium on Statistical Aspects of Fatigue, Am. Soc. Testing Mats. (1951). (Issued as separate publication *ASTM STP No. 121.*) Symposium on Fatigue with Emphasis on the Statistical Approach, II, Am. Soc. Testing Mats. (1952). (Issued as separate publication *ASTM STP No. 137.*)

(12) J. B. Scarborough, "Numerical Mathematical Analysis," Second Edition, Johns Hopkins Press, Baltimore, Md., pp. 463–465 (1950).

(13) T. J. Dolan and H. F. Brown, "Effect of Prior Repeated Stressing on the Fatigue Life of 75S-T Aluminum," Technical Report 29, ONR Project No. NR-031-005, University of Illinois, April, 1952. Also *Proceedings*, Am. Soc. Testing Mats., Vol. 52, p. 733 (1952).

(14) E. J. Ward and D. C. Schwartz, "Investigation of Prot Accelerated Fatigue Test," WADC Technical Report 52-234, Materials Laboratory, Wright Air Development Center, November, 1952.

(15) E. Marcel Prot, "Essais de Fatigue sous charge progressive, Etude de la dispersion des résultats," *Révue Générale de Mécanique*, Janvier, 1953.

(16) F. B. Stulen and W. D. Lamson, "Preliminary Report of the Progressive-Load Method of Fatigue Testing," Unpublished report, Curtiss-Wright Corp., Propeller Div., April, 1951.

(17) N. Arley and K. R. Bush, "Introduction to the Theory of Probability and Statistics," John Wiley and Sons, Inc., New York, N. Y., Article 6.5 and Chap. 12 (1950).

DISCUSSION

Mr. E. J. Ward[1] (*presented in written form*).—The most important advantage of the Prot method is that every test results in a failure. As the authors have pointed out, at the low loading rates the numbers of cycles and times required are comparable to conventional fatigue testing. The low loading rates appear to us to be the most desirable to use so as to reduce the effect of any errors in extrapolating and to eliminate any effects of internal heating or plastic deformation, which may occur at high loading rates. Therefore, the time to conduct each test is not appreciably less in the Prot method. But, as the authors have also pointed out, the scatter in the endurance limit can be determined with the use of a relatively few specimens. The desire to determine the endurance limit of each component tested led the propeller manufacturers to step up the stress and retest the component again until failure occurred. This resulted in a stepwise Prot-type test which was used even before Prot published his method. It appears that the Prot method can be used to advantage for comparative fatigue tests even if the true mean endurance limit (or fatigue strength at a large number of cycles) cannot be predicted. An example of this is an investigation conducted in the Materials Laboratory of the Wright Air Development Center. It was desired to determine the optimum bumping pressure for flash welding a titanium alloy. Three groups of fatigue test specimens were manufactured using a high, intermediate, and low bumping pressure, respectively, in the welding process. Prot-type tests were run, using the same starting stress and loading rate for all three groups. No attempt was made to predict the endurance limit, but the average failure stresses and statistical variations were compared and the pressure to be used chosen on the basis of the highest average and least scatter. If caution is used, the Prot method is apparently a very useful tool in such investigations.

Mr. Frank A. McClintock.[2]—The authors' first conclusion stated that the Prot method gives information only about the endurance limit. While this is true as Prot's theory stands, the finite life portion of the curve can be back-calculated, using Henry's theory. Let S_0 be the starting stress and ν the number of cycles, so that

$$S = S_0 + \alpha\nu \quad \text{............} (1)$$

Now if

$$N = k(S - S_e)^{-m} \quad \text{for} \quad S > S_e,$$

$$N = \infty \quad \text{for } S \leq S_e \quad \text{....} (2)$$

then from Miner's hypothesis,

$$1 = \int \frac{d\nu}{N} = \int_{S_e}^{S_R} \frac{dS}{\alpha k (S - S_e)^{-m}}$$

$$= \frac{1}{(m+1)k\alpha} (S_R - S_e)^{m+1} \quad \text{....} (3)$$

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[1] Chief, Fatigue and Creep Rupture Section, Materials Laboratory, Wright Air Development Center, Dayton, Ohio.

[2] Assistant Professor of Mechanical Engineering, Massachusetts Institute of Technology, Cambridge, Mass.

Hence, letting $\frac{1}{m + 1} = n$,

$$\mathrm{d}S_R/\mathrm{d}\alpha^n = (k/n)^n \qquad (4)$$

Thus if n and S_e can be found from Prot data, k can be found from the slope, and N can be calculated for ordinary tests at any S from Eq 2.

An alternative analysis may be based on the assumption that

$$NS^m = k \quad \text{for} \quad S > S_e ,$$

$$N = \infty \text{ for } S \leq S_e \qquad (5)$$

Then

$$1 = \int \frac{\mathrm{d}\nu}{N}$$

$$= \int_{S_e}^{S_R} \frac{\mathrm{d}S}{k\alpha S^m} = \frac{S_R^{m+1} - S_e^{m+1}}{(m + 1)k\alpha} \qquad (6)$$

Hence, letting $1/(m + 1) = n$, a plot of $S_R^{1/n}$ *versus* α should be a straight line, and k can be estimated from its slope:

$$\frac{\mathrm{d}S_R^{m+1}}{\mathrm{d}\alpha} = \frac{k}{n} \qquad (7)$$

When these data are applied to estimate the ordinary S-N curve from Prot data, the results are rather mixed. For instance, for the 14B50 steel unnotched specimens, the various results are as shown in the accompanying Fig. 17. Note the strong dependence on the value of n. As shown below, it appears doubtful that the values of 0.456 and 0.717 for n in Eq 4 are significantly different. For other materials, the estimates of the ordinary S-N curve from the Prot data are sometimes better and sometimes worse than for the 14B50 steel. Thus Prot data can give some idea of the finite life part of the S-N curve, even though they would not normally be used for that purpose.

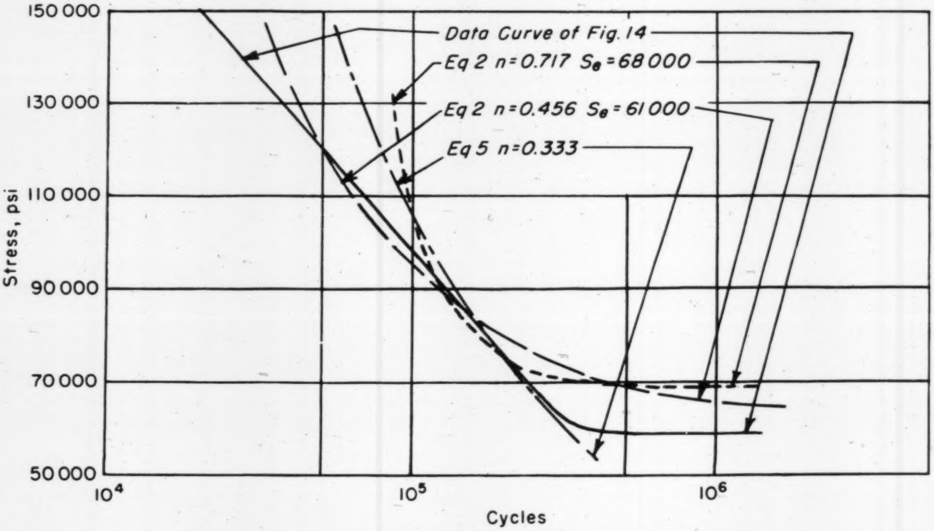

FIG. 17.—S-N Curves for 14B50 Steel Unnotched Specimens.

One point in the statistical interpretation of the data may require clarification. The standard deviation shown in Fig. 16 is the standard deviation of the estimate of the mean rupture stress, σ_{S_R}. Its value at $\alpha = 0$ is the standard deviation of the estimate of the mean endurance limit, σ_e. Individual specimens have endurance limits which vary about the mean endurance limit, and this variation may be described by its standard deviation, σ. The authors assumed in making the estimates shown in Fig. 16 that the standard deviation of rupture stresses about the mean line was independent of α and hence equal to σ. The estimate of σ is not affected by the choice of a minimum value of α, although σ_e, the standard deviation of the estimate of the mean endurance limit, is so affected. It happens that these two quantities were almost the same for the data of Fig. 16, namely $\sigma_e = 4900$ psi and $\sigma = 4350$ psi. Thus the conclusions about the reasonableness of the standard deviation of the endurance limit still hold, even though the concern about its dependence on α is unfounded.

TABLE V.—CONFIDENCE LIMITS FOR EXPONENTS AND ENDURANCE LIMITS.

Material	Specimen Type	Starting Stress, psi	Exponent n	Endurance Limit, psi	Standard Deviation of Endurance Limit, σ, psi	Estimated 95 per cent Confidence Limits for Endurance Limit with n Known, psi
75S-T6 Aluminum Alloy	Unnotched	20 000	0.16 ± 0.14	18 000 ± 20 000	2600	±2600
Ingot Iron B	Unnotched	10 000	0.36 ± 0.92	26 000 ± 20 000	1500	±4000
Ingot Iron A	Unnotched	10 000	1.07 ± 0.84	38 000 ± 1800	1500	±1400
14B50 Steel	Notched	35 000	0.56 ± 0.34[a]	39 000 ± 11 000[a]	4400	±3000

[a] Based on first approximation. Confidence limits may be about 15 per cent too broad.

While the conclusions regarding coaxing seem reasonable *a priori*, they are not established by the data. Using Sugi's interesting statistical analysis, the results shown in the accompanying Table V are obtained. The 95 per cent confidence limits for the exponent and the mean endurance limit are taken to be twice the standard deviations of the estimates of these quantities. The limits for the mean endurance limit are so broad that no conclusions regarding coaxing can be drawn. As for the values of the exponents, neither those chosen by the authors nor, except in the case of aluminum, the value 0.5 can be disproved.

When the exponent n is known, as for example from conventional data, the standard deviation of the estimate of the endurance limit is much easier to obtain, namely,

$$\sigma_e = \sigma \sqrt{(1/r) + (\overline{\alpha^n})^2 \Big/ \sum_{i=1}^{r} (\alpha_i^n - \overline{\alpha^n})^2}$$

where r is the number of points.[3] In Table V, 95 per cent confidence limits for the mean endurance limit estimated from this expression are also given. Although these limits are smaller, it is still not possible to draw definite conclusions regarding the effect of coaxing on the mean endurance limit. On the other hand, there is little doubt that at high values of α there is a dependence of S_R on σ_0.

The authors have done a real service in showing how, with the Prot method, an estimate of the precision of the results can be obtained even with relatively few specimens. While the endurance limit so determined may not be in exact agreement with that obtained from ordinary tests, neither method can be claimed superior to the other for estimating service performance where the loads are varying in an irregular manner. By the time service performance can be related to either type of data, it can be related to both, since they are both special cases of loading histories.

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[3] W. J. Dixon and F. J. Massey, "Introduction to Statistical Analysis," McGraw-Hill Book Co., Inc., New York, N. Y., p. 158 (1951).

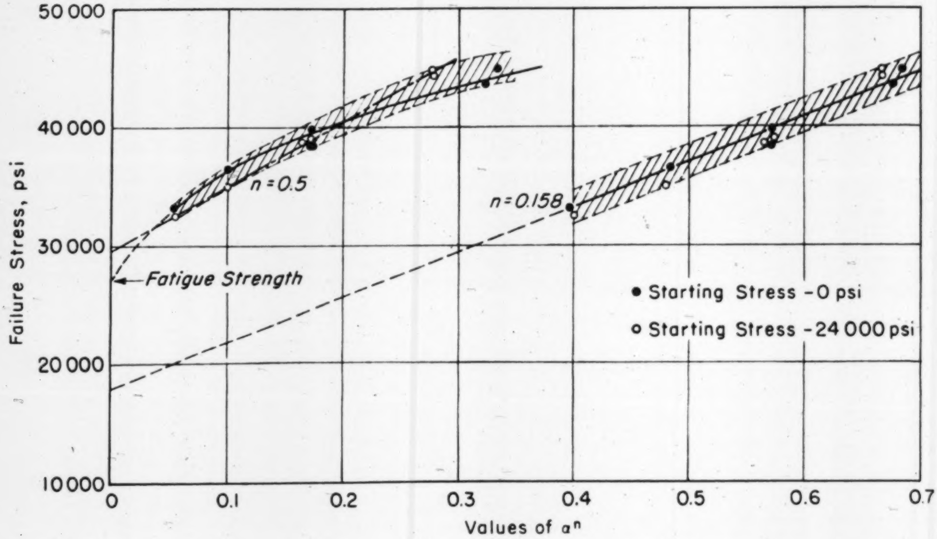

FIG. 18.—Failure Stress of 24 S-T 4 Aluminum as a Function of Loading Rate (psi per cycle) to the Power n for $n = 0.5$ and $n = 0.158$.

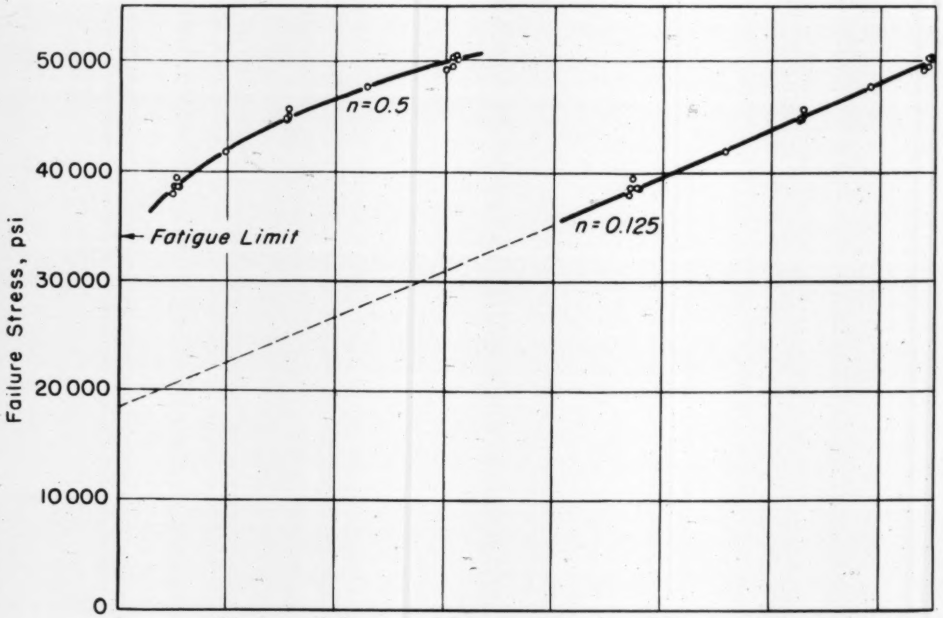

FIG. 19.—Failure Stress of Mild Steel as a Function of Loading Rate (α psi per cycle) to the Power n for $n = 0.5$ and $n = 0.125$.

MR. B. J. LAZAN.[4]—There has been considerable discussion recently regarding the reliability and usefulness of the Prot-type method for fatigue testing and the authors have contributed significantly towards clarifying this matter. Since recent work at Minnesota partially confirms and supplements some of the data reported by the authors, a few of the Minnesota results are reviewed below.

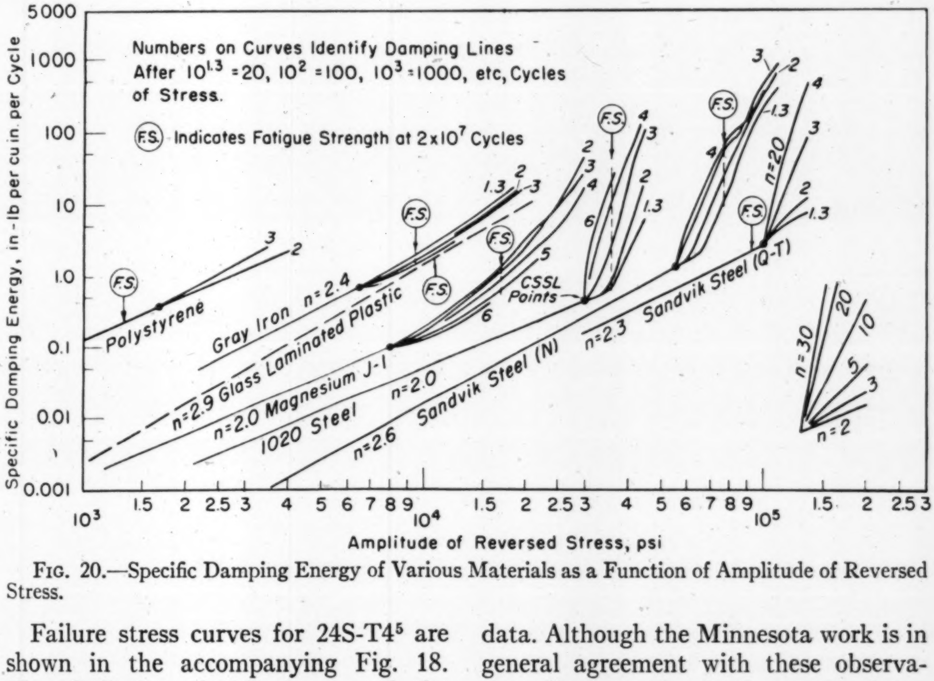

FIG. 20.—Specific Damping Energy of Various Materials as a Function of Amplitude of Reversed Stress.

Failure stress curves for 24S-T4[5] are shown in the accompanying Fig. 18. The similarity of this figure and the authors' Fig. 2 is apparent. The value of n which results, statistically, in the straightest line for failure stress is 0.158, as compared to the authors' value of n of 0.178. Furthermore, the strength (18,000 psi) predicted by the $n = 0.158$ line is substantially lower than the fatigue strength of the material (27,000 psi) found by conventional fatigue tests. This observation and the resultant conclusion regarding the unreliability of the Prot method for this type of material also confirm the authors' finding.

The authors in their conclusions state (*a*) that the Prot method appears to be more promising for ferrous metals and (*b*) that a modified approach, in which a value of exponent n is selected to produce the straightest line, results in better agreement with conventional fatigue data. Although the Minnesota work is in general agreement with these observations (for example, the Prot method was found very reliable for 4340 steel), it is important to realize that there may be exceptions. For example, Fig. 19 shows that for mild steel[6] the modified Prot approach (which gives an exponent n of 0.125) predicts a fatigue limit of 18,000 psi, which is substantially below that (34,000 psi) determined by conventional fatigue tests.

One of the objectives of the Minnesota

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[4] Professor of Materials Engineering, University of Minnesota, Minneapolis, Minn.

[5] B. J. Lazan and F. Vitovec, Status Report 53-2 to Wright Air Development Center for Contract AF 33(038)-20840 and AF33(616)-88, April 1, 1953.

[6] B. J. Lazan and F. Vitovec, Status Report 53-3 to Wright Air Development Center for Contract AF 33(038)-20840 and AF33(616)-88, June 1, 1953.

program on the Prot approach is to clarify coaxing effects and their relationship to Prot starting stress. The approach being used is to attempt to relate the stress beyond which coaxing effects occur to the cyclic stress sensitivity limit determined from damping energy studies. This work is briefly discussed below.

If the specific damping energy absorbed by a material[7] is plotted as a function of stress, then curves similar to those shown in Fig. 20 result. Tests on approximately twenty materials and temperatures indicate that:

1. At low stress damping is independent of number of stress cycles.

2. At high stress damping is affected by number of cycles. Damping may either decrease or increase (compare, for example, magnesium and mild steel in Fig. 20) and in some cases the change may be very large (increases as large as 30 times and reductions as large as 99 per cent having been observed at the fatigue strength).

3. The point below which no stress history effects are observable and above which damping may change with number of stress cycles has been labeled the "cyclic stress sensitivity limit" for damping (see solid dots in Fig. 20 and "CSSL" mild steel curve).

4. All metals studied to date display a cyclic stress sensitivity limit. These occur at from 33 to 1.06 per cent of the fatigue strength at 2 × 10^7 cycles. However, all but four (of twenty) cases fall in the range from 45 to 90 per cent, the average location being at 80 per cent.

The Minnesota work is attempting to determine if coaxing effects are confined to stresses above the cyclic stress sensitivity. To date a 24S-T4 aluminum alloy and 1020 steel have been partially studied, and these metals show no significant difference in Prot strength whether the starting stress is zero or the cyclic stress sensitivity limit. Work is now in progress at starting stress between the cyclic stress sensitivity limit and the fatigue unit.

MESSRS. H. T. CORTEN, T. DIMOFF, AND T. J. DOLAN (*authors' closure*).—The authors wish to thank the discussers for their comments and contributions.

Mr. Ward has suggested a connection between the step-up method and the Prot method of fatigue testing with which the authors concur. As a comparison type of test, the step-up method possesses several desirable characteristics. However, as Mr. Ward cautions (and the Prot analysis suggests) the fracture stresses obtained by the step-up method may be slightly higher than the endurance limit obtained from conventional tests. Only if coaxing is absent and the number of cycles in each step is sufficiently large (possibly 10^7 cycles), does it appear reasonable to expect that the fracture stress data obtained from the step-up method will agree with the endurance limit obtained from conventional tests.

Mr. McClintock has demonstrated clearly, by employing Henry's analysis, that the finite life portion of the *S-N* diagram may be determined approximately by using only progressively increasing load data. The authors conclusions that "the Prot method gives information about the endurance limit only" was intended to emphasize the fact that the primary usefulness of the Prot method is to concentrate all of a limited number of specimens upon obtaining information about the endurance limit. As there are now in use a number of methods of planning, running, and analyzing fatigue experiments, each developed to take advantage of special features of the experiments, it seems desirable, even necessary, to make the advantages of the various methods entirely clear.

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[7] B. J. Lazan, "Fatigue Failure Under Resonant Vibration Conditions," Wright Air Development Center Technical Report 54-20, March, 1954.

In his discussion of the significance of the standard deviation of the endurance limit, Mr. McClintock has emphasized the difference between the standard deviation of the rupture stresses, σ_{S_R} at the various values of α, and the standard deviation at various values of α of the line of best fit (based on a least square analysis. In the analysis, the standard deviation of S_R was assumed to be constant for all values of α. With this information the line of best fit was computed by the least square analysis. This procedure gives the most probable line. Other lines of smaller probability are possible, and the dashed lines in Fig. 16 indicate the bounds of one standard deviation on the position of these lines. The reason that this band became wider at the extremities of the data (high and low values of α) becomes clear by considering that for a given value of n, two degrees of freedom of position of the line remain, vertical translation up or down and rotation about the mean value of α and S_R. As some uncertainty exists as to the mean value of S_R and also the slope of the line, limits of one standard deviation, including both of these uncertainties, lead to a wider band at the extremities. Thus, the reliability of the estimate of the mean endurance limit (68 per cent confidence limits on mean) is indicated by the standard deviation of S_e and varies with α as indicated by the dashed lines in Fig. 16. The scatter of the fracture stress data is the only indication of the standard deviation of the endurance limit that is possible based on this analysis.

The authors agree with McClintock's contention that the influence of coaxing has not been proved statistically. However from the practical point of view of one who wished to use the Prot method, the influence of coaxing is evident in the data for ingot iron.

The rather broad confidence limits, even when n is assumed to be known, serve as a useful reminder of the degree of reliability that can be attached to the results.

Recently, evidence has been obtained[8] that indicates that the coaxing phenomenon may be very sensitive to small temperature changes. Since the ingot iron, when tested at the higher values of α, heated a noticeable amount (150 F), it is likely that the influence of coaxing was different at different values of α. However, at the present time it is not possible to predict time-temperature-stress combinations that result in the maximum influence of coaxing in a progressively increasing load experiment. This, plus the difficulty of establishing the influence of coaxing on a statistical basis, increases the complexity of the study of the relation between coaxing and the cyclic stress sensitivity limit mentioned by Lazan. From the studies of the coaxing or strain aging phenomena[9] that have been made it appears that repeated localized slip, which normally leads to the initiation of a fatigue crack, is inhibited or entirely stopped due to the diffusion of carbon and nitrogen into these regions. If the damping that Lazan is studying is also associated with localized slip, it appears that the two phenomena may be related. However as the damping in many low carbon steels apparently increases with numbers of cycles, and strain aging and inhibition of slip are also believed to increase with number of cycles, the relation between coaxing and damping may be very complex.

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[8] Unpublished work of F. Rally and G. M. Sinclair at the University of Illinois.

[9] J. C. Levy and G. M. Sinclair, "An Investigation of Strain Aging in Fatigue" Technical Report 39, ONR Project NR-031-005, T.A.M. Dept., University of Illinois, Urbana, Ill. (1954).

The authors were gratified to hear that the work at Minnesota on 24S-T6 aluminum and SAE 4340 steel confirms the results presented in this paper. The results for the mild steel are the first instance that the authors have encountered in which the agreement was so poor for a ferrous metal. In this connection it is interesting to note that the value $n = 0.125$ is unusually small. Employing conventional data and Henry's analysis the average value of n that the authors encountered was approximately 0.4, and the smallest value was approximately 0.3. These values of n do not produce appreciably different estimates of the endurance limit from $n = 0.5$ as may be observed from Figs. 7 and 8. In Fig. 19 it appears that if the curve for $n = 0.5$ were extrapolated to $\alpha^n = 0$, the results of the Prot and conventional data would be in good agreement. This would likely be true for $n = 0.4$ also. In those cases where a small value of n has been required to obtain a linear relation between S_R and α^n, the agreement between the Prot and conventional data has not been satisfactory. On the other hand when the S_R *versus* α^n relation exhibits marked curvature, extrapolation is very uncertain. Consequently it appears that a value of n from 0.3 to 0.5 may be generally usable for a ferrous metal and affords reasonable agreement insofar as can be determined from all of the available data.

INVESTIGATIONS CONCERNING THE FATIGUE OF AIRCRAFT STRUCTURES*†

By Robert A. Carl[1] and Thomas J. Wegeng[1]

Synopsis

The loads imposed on the structures of combat military airplanes during maneuvering flight are sufficiently high to require consideration of the likelihood of a major fatigue failure occurring during the service life of the airplane. The Bureau of Aeronautics has sponsored laboratory investigations regarding the fatigue characteristics of three designs of naval airplanes during the past three years. *S-N* curves for certain major structural components of these airplanes have been determined and in one instance a modification was developed to increase the fatigue life of a wing structure. The results of an investigation of the cumulative damage effect of a spectrum loading on an aircraft outer wing panel are presented. An analysis of composite stress concentration factors present in several structural components is also included in this paper.

In 1950, the Bureau of Aeronautics, Department of the Navy, became seriously concerned regarding the cause of several in-flight accidents of attack-type airplanes which could not be satisfactorily attributed to the usual causes for such accidents. It was determined that, during the performance of dive-bombing and rocket-launching maneuvers, squadrons operating these airplanes were frequently exceeding flight restriction limits. It was found that some of these airplanes had exceeded design limit load conditions as many as twenty times. Accordingly, a project was initiated at the Aeronautical Structures Laboratory, Naval Air Material Center, to determine the effect of accelerations in excess of design limit load on the service life of the structure. When it was found that several outer wing panels could be made available for testing under this project, the load range was extended to include values below limit load so as to permit the accumulation of sufficient data to obtain an *S-N* curve for the outer wing panel of this attack-type airplane.

Prior to completion of the repeated-load tests of this airplane, a crash of a piston-engine fighter airplane and the subsequent inspection of several similar airplanes awaiting overhaul indicated that fatigue might be a possible explanation for this crash. At that time these airplanes were being used for intensive training in ground-support tactics, and

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† The statements and views expressed in this paper are those of the authors and are not to be construed as official or necessarily representing the views of the Bureau of Aeronautics, Department of the Navy.

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it was standard practice to perform twelve or more rocket launching runs with pullout accelerations near design limit load conditions during each hour of flight. Accordingly, a large number of high load level pullouts were rapidly accumulated by the airplanes. A test program was undertaken, therefore, for the dual purpose of obtaining information concerning the capability of the wings of this type of airplane to withstand repeated applications of loads representing high-acceleration pullouts and of determining the structural change to the wing center section required to increase the useful life of the airplanes.

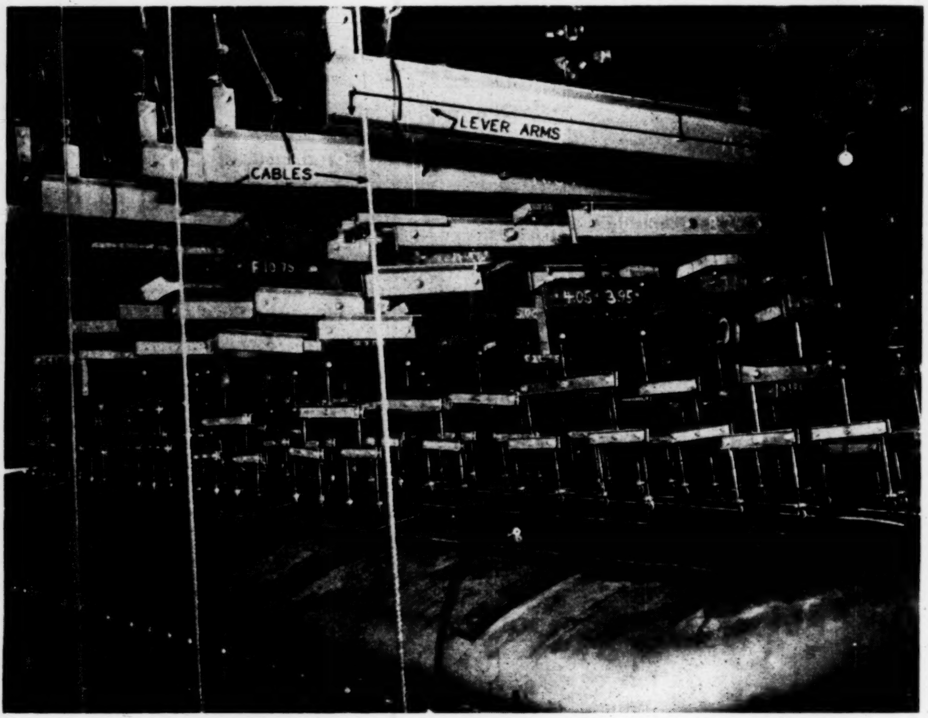


FIG. 1.—Typical Test Setup for Applying Loads to Aircraft Wing Test Specimens.

The question then arose concerning the fatigue characteristics of the wing structures of the more modern jet-type aircraft. The trend in recent years has been constantly toward aircraft structures having increased mean stress levels, and this trend, viewed in the light of the test results obtained under the two previous programs, indicated that fatigue might be a serious factor in the operation of jet-engine fighters. It was possible to obtain twelve outer wing panels for this type of airplane, and tests were performed to determine an S-N curve for this structure and to obtain information concerning Miner's cumulative damage ratio.

TEST PROCEDURE

All the test specimens used in these investigations were complete aircraft wing structures or portions of a wing such as the outer wing panel (that is, the portion outboard of the wing fold line) that were believed susceptible to fatigue failure. In all tests the specimens were mounted in a manner that duplicated the root-end restraint of the structure as mounted on the airplane. Beam bending loads were applied to the test specimen through a tension-patch, whiffletree, and hydraulic-jack loading system, and chordwise loads were applied through felt-lined straps cemented to the panel at appropriate spanwise intervals. Figure 1 shows a typical test setup of this type. For static tests, the loads were applied to the hydraulic loading system by means of hand-operated pumps. For repeated-load tests, these pumps were replaced by motor-driven pumps, and the loads were controlled by a calibrated tension loop, equipped with upper and lower load limit microswitches which operated a solenoid-controlled, hydraulically-actuated by-pass valve. By this means the load was automatically cycled between the upper and lower load limits for the test being performed. All the tests were conducted with the lower stress level held constant at a value corresponding to a load of 1 *g*, and the value of the upper load level was varied from panel to panel. The frequency of loading varied from approximately 4 cpm at 60 per cent limit load to 2 cpm at 120 per cent limit load.

All test loads applied to the test specimens were determined from the design loads for the basic airplane. The term "design limit load," or simply "limit load," defines the load, or combination of loads, which establishes the strength level required of a structure to permit the aircraft to perform safely certain specified maneuvers. Airplanes usually are designed to support 1.15 times limit load without yielding and 1.5 times limit load without failure. Thus, the stress level in a critical member or members of the structure at limit load is approximately 67 per cent of the ultimate strength of the material of that member or those members. Accordingly, it is possible to use the term limit load to define the general stress level in a structure and to plot cycles-to-failure curves for the structure using this parameter as the ordinate in the graph. This procedure is followed throughout this paper.

TEST PROGRAMS AND RESULTS

Piston-Engine Attack Airplane:

The first test program utilized outer wing panels from a piston-engine, propeller-driven, low-wing attack airplane. It is referred to hereinafter as an attack airplane and in the tables and figures it is designated the PA airplane.

The testing condition chosen for this program was representative of a positive low angle of attack (c.g. aft) pullout in which one of the 500-lb bombs mounted on the wing racks had been dropped, but the bomb on the opposite wing had not, thus requiring a small amount of aileron displacement to maintain symmetrical flight. The normal gross weight of the airplane was used in computing the applied loads so that the 100 per cent limit load condition represented an acceleration of 7 *g*.

A static test was first performed to determine the static strength of the outer wing panel under these loading conditions. The failure occurred when 154 per cent limit load was applied. The failure apparently originated in the lower wing skin immediately aft of the main beam at station 160 and was followed by a tension failure of the lower main beam capstrip at station 162. These station numbers refer to spanwise locations on the wing measured in inches from the center line of the airplane.

TABLE I.—SUMMARY OF RESULTS OF REPEATED-LOAD TESTS OF ATTACK AIRPLANE WING OUTER PANELS.

Panel	Upper Load Level		Initial Skin Crack, Cycles	Initial Horizontal Crack in Lower Spar Cap, Cycles	Complete Failure, Cycles	Remarks[e]
	g	Per cent of Limit Load				
No. 1.....	10.5	154	Not observed	Not observed	1	Static test panel. Skin failed at station 160. Spar failed at station 162.
No. 2.....	8.4	120	800–994	[d]	1046	Lower surface skin failed in tension at station 160 of the outer wing panel. Skin crack was first noticed at 994 cycles. Panel was previously inspected at 800 cycles and no cracks were visible.
No. 3.....	7.7	110	[d]	690	696	Main beam web buckled in region of station 150. Upper and lower spar caps cracked horizontally in this region. Failure was complete.
No. 4.....	6.3	90	2302	2023	4302	Lower spar cap failed in tension at station 158.
No. 5.....	7	100	1898	[b]	3430	Lower spar cap failed in tension at station 147. Lower spar cap cracked but history of the crack is unknown. Crack was first noticed at 1898 cycles.
No. 6.....	7.7	110	1005	[b]	1272	Lower spar cap failed in tension at station 162. Spar cap cracked but history of the crack is unknown. Crack was first noticed after 1174 cycles.
No. 7.....	7	100	1738	1238	1889	Lower spar cap failed in tension at station 147.
No. 8.....	5.6	80	6660	3665	8178	Lower spar cap failed in tension at station 181.5.
No. 9[a]....	5.6	80	[c]	2985	[c]	Test was discontinued after 6500 cycles were applied.

[a] Panel was modified to include gun installation.
[b] Not known when crack first appeared.
[c] Did not occur up to 6500 cycles.
[d] Did not occur prior to complete failure.
[e] Station numbers represent spanwise locations on wing measured in inches from wing centerline.

Repeated-load tests were then performed with one panel at a time installed on a wing center section which was used as a mounting jig. A total of nine ouser wing panels, including the static test panel, were tested in the program and the data obtained are shown in Table I and graphically presented in Fig. 2. Repeated-load tests were performed on eight of the panels at loads varying from 1 *g* (14 per cent limit load) to 80, 90, 100, 110, and 120 per cent limit load.

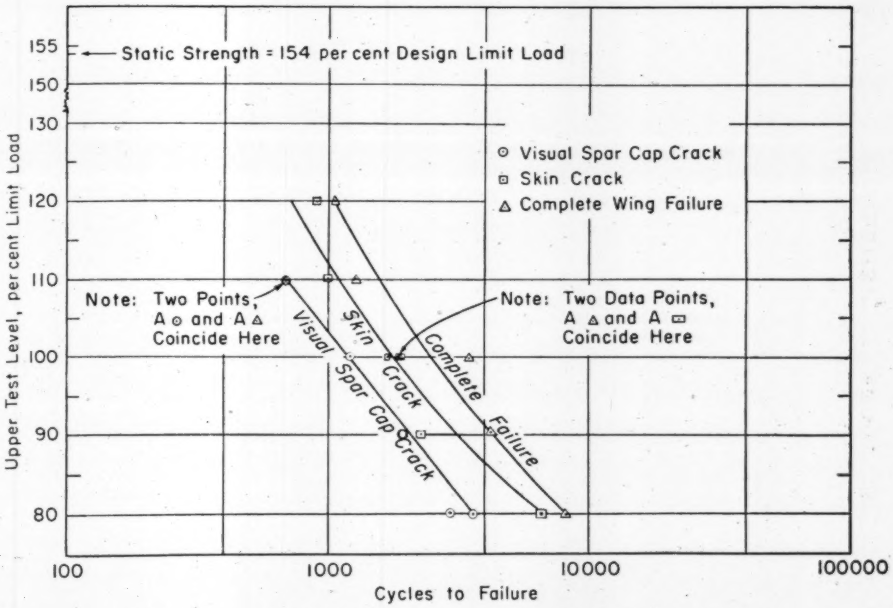


FIG. 2.—Repeated-Load Tests of Attack Airplane Outer Wing Panels.

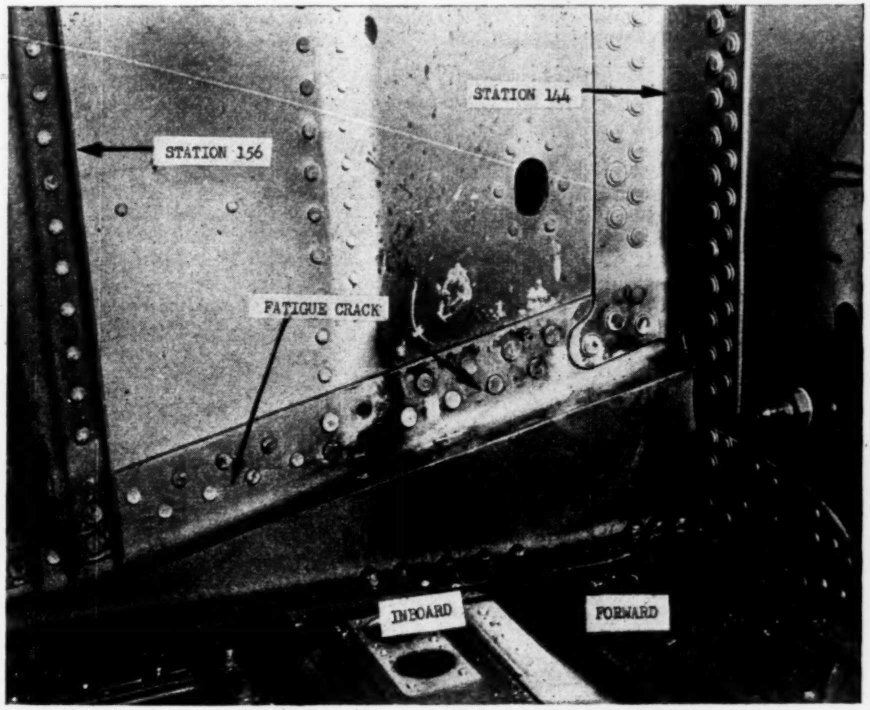

STATION 144
STATION 156
FATIGUE CRACK
INBOARD
FORWARD

FIG. 3.—Location of Fatigue Crack in Attack Airplane Wing Spar Cap.

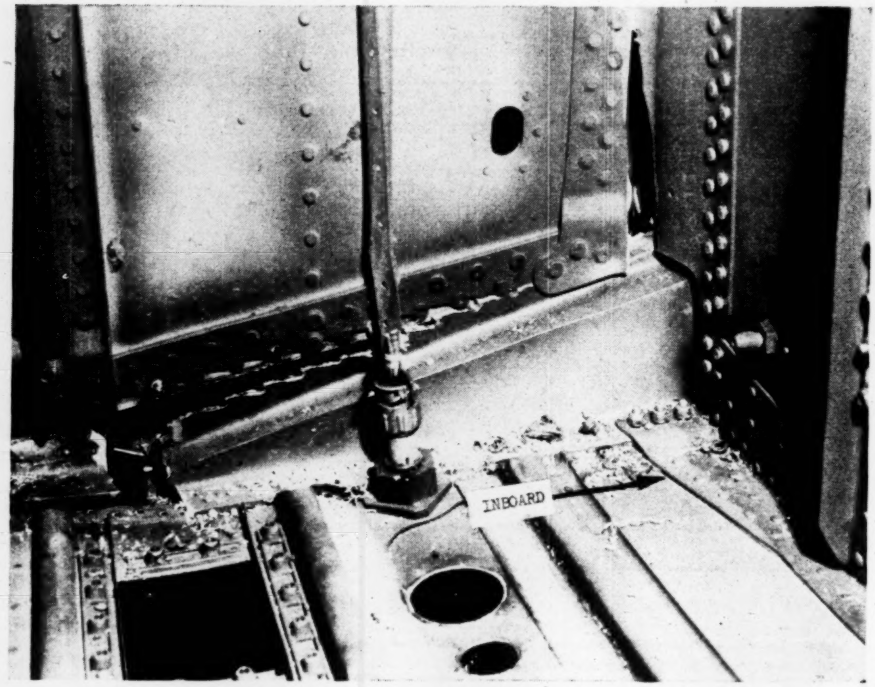


FIG. 4.—Typical Final Fatigue Failure of Attack Airplane Wing.

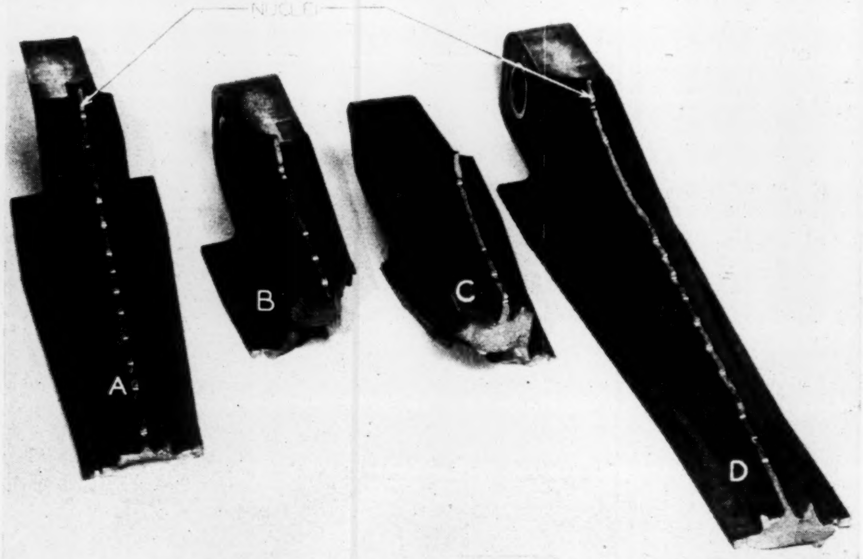

NUCLEI
A
B
C
D

FIG. 5.—Variation in Final Fatigue Failure Location of Attack Airplane Wing Spar Cap.

It will be noted that the first six panels are structurally similar while panels 7 and 8 differ slightly in that they were modified to adopt different rocket launching racks. Panel 9 was modified to include a cannon installation in addition to the rocket launching racks. These modifications do not appear to have had an appreciable effect on the fatigue life of the panels since the data from the tests fall within the scatter band for the other panels. It is apparent from these data that the lower spar cap crack would be the first indication of fatigue damage. This would be followed by cracking of the tension skin and then by total failure of the panel. Figure 3 is a photograph of the lower capstrip of the outer wing panel showing the location of typical cracks induced by the repeated-load tests. A typical final failure of the wing is shown in Fig. 4, and Fig. 5 shows the variation in location of the final tension failures in the lower spar cap.

TABLE II.—SUMMARY OF REPEATED-LOAD TEST DATA FOR THE ATTACK AIRPLANE CENTER SECTION LOWER HINGE FITTINGS INSTALLED ON AIRPLANE.

Center Section	Starboard Fittings		Port Fittings	
	Upper Load (Per Cent of Limit Load)	N, cycles	Upper Load (Per Cent of Limit Load)	N, cycles
No. 1	120	1046	100	3430
	110	696	110	1054
	90	2020		
		3762[a]		4484[d]
No. 2	90	2282	110	218
	100	1620		
		3902[b]		
No. 3	100	269		
	80	8599		
		8868[c]		
No. 4	80	6079		

[a] Fitting No. 1 starboard, total plotted at 102 per cent limit load in Fig. 6.

[b] Fitting No. 2 starboard, total plotted at 94 per cent limit load in Fig. 6.

[c] Fitting No. 3 starboard, total plotted at 80 per cent limit load in Fig. 6.

[d] Fitting No. 1 port, total plotted at 102 per cent limit load in Fig. 6.

During the performance of these tests, it became apparent that the wing center section lower hinge fitting was similarly subject to failure from fatigue. The data obtained from the failures of these fittings while installed in the wing center section are shown in Table II. It will be noted that most of these fittings have been subjected to tests at more than one load level; hence, the appropriate point to plot these data on an S-N curve may be open to some question. For Fig. 6, the composite load level was chosen by multiplying the number of cycles at each load level by the load level and dividing the sum of the products by the total cycles to failure.

To supplement these data further, additional hinge fittings were tested under repeated-load conditions in a jig. The jig was designed to simulate the fitting installation in the wing center section. The plot of the data from the jig-mounted tests is contained in Fig. 6. For comparison purposes, the plot of the final failure of the outer wing panel is also shown in Fig. 6. It will be noted that these center section lower hinge fittings are probably more critical than the outer wing panels for repeated applications of flight loads below 90 per cent design limit load.

Piston-Engine Fighter Airplane:

For the second test program, four piston-engine fighter airplanes were obtained for testing. These airplanes are referred to hereinafter merely as fighter airplanes and in the tables and figures are designated by the letters PF. Cracks in the spar web near the wing-fuselage juncture strongly suggested the possibility of fatigue as a cause for failures in the wing structure of this type of airplane, particularly in view of the repeated-load test data being accumulated at that time on the attack airplane.

All of the test airplanes had been in service for a considerable period of time. As a consequence, the portion of the life of the structure which had been "used up" during the service employment of the airplanes could only be estimated. An approximation of this service experience was obtained from an analysis of the log book for each airplane. This was done by appropriately weighting each of the flight categories which involve high-acceleration maneuvers so as to obtain an approximation of the number of limit load pull-outs experienced by each airplane. The airplanes were tested in the "as-received" condition. Two of the airplanes had cracks in the main spar web (beneath web doubler plates) on both starboard and port sides extending upward and inboard for approximately 2 to 3 in. from the lower intersection of the wing and fuselage as shown in Fig. 7. The third airplane had a crack in the main spar web at approximately station 15, again measured in inches from the center line of the wing, extending approximately 9 in. up from the fuel strainer inlet hole. The fourth airplane had no visible cracks in the spar web. In addition to these defects, there was rivet slippage of the skin attachment rivets along the upper and lower spar caps immediately outboard of the fuselage on all four airplanes.

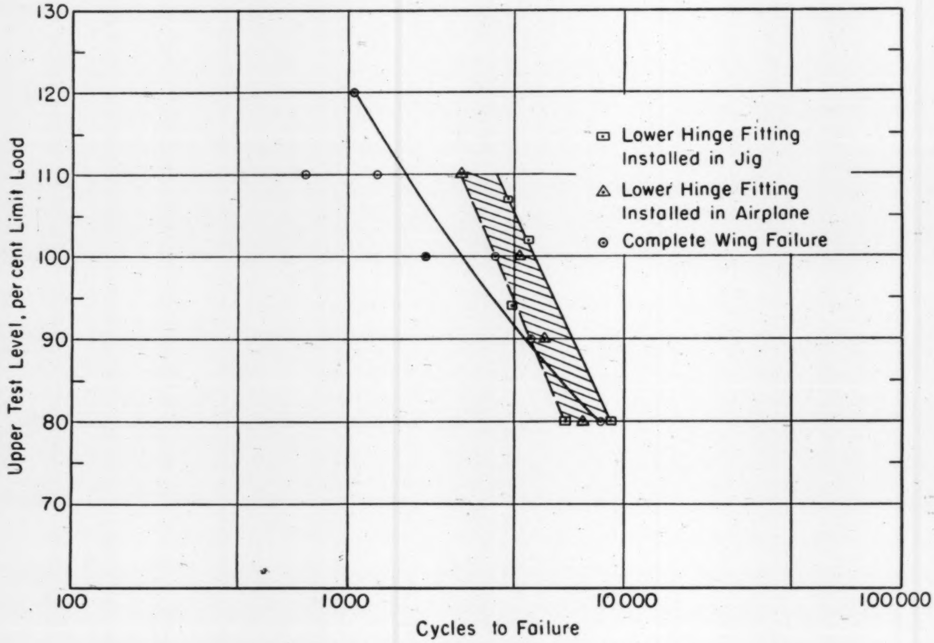


FIG. 6.—Repeated-Load Tests of Attack Airplane Wing Center Section.

The test method employed for these tests was generally similar to that used for the attack airplane with the exception that loads were applied to the entire fighter wing rather than to the outer panel of one side only. The airplane was supported in the test jig at two points; the forward point was at the fuselage armor plate and the rear support was at the tail wheel axle. The fittings at these points, which were pinned to suitably braced columns, permitted the fuselage to roll and pitch but restrained it from yawing. The wing drag loads were reacted at the arresting hook. Engine mount loads were applied through the engine mounts by the use of a blower housing. All repeated-load tests were conducted between limits of 1 *g* and 6.3 *g* (100 per cent limit load).

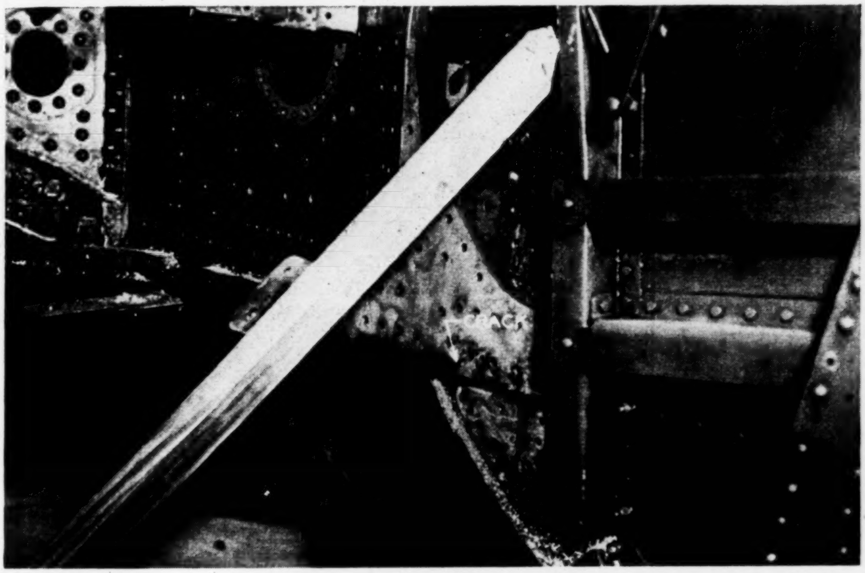


FIG. 7.—Crack in Spar Web of Fighter Airplane Prior to Initiation of Repeated-Load Tests (Typical of Two Test Airplanes).

In addition to information concerning the ability of these airplanes to withstand repeated applications of limit load, information was also desired as to the effect of the above-mentioned service-imposed structural discrepancies on the static strength of the airplane. Accordingly, repeated-load tests on the first airplane were stopped after 2003 cycles and a static test was performed. The wing satisfactorily supported 143 per cent limit load (9.0 *g*) and tests were stopped at this point.

The second airplane was tested under repeated-load conditions. During cycle 517, 18 rivets attaching the lower inboard skin to the lower capstrip sheared and the corresponding rivets on the upper capstrip were slipped. In an attempt to load the structure for cycle 518, the lower capstrip of the port wing failed about 5 in. outboard of the fuselage. The failure was then repaired and the port and starboard loads interchanged. (Port side loads were slightly higher because of engine torque loading.) A static test was performed and failure occurred at 158 per cent limit load (9.95 *g*) through the section where the firewall (spar-web) crack occurred in service. A third repeated-load test was then performed on another airplane with the failure occurring after 1484 cycles of limit load at the same location where the static test failure occurred on the second airplane. This failure is shown in Fig. 8.

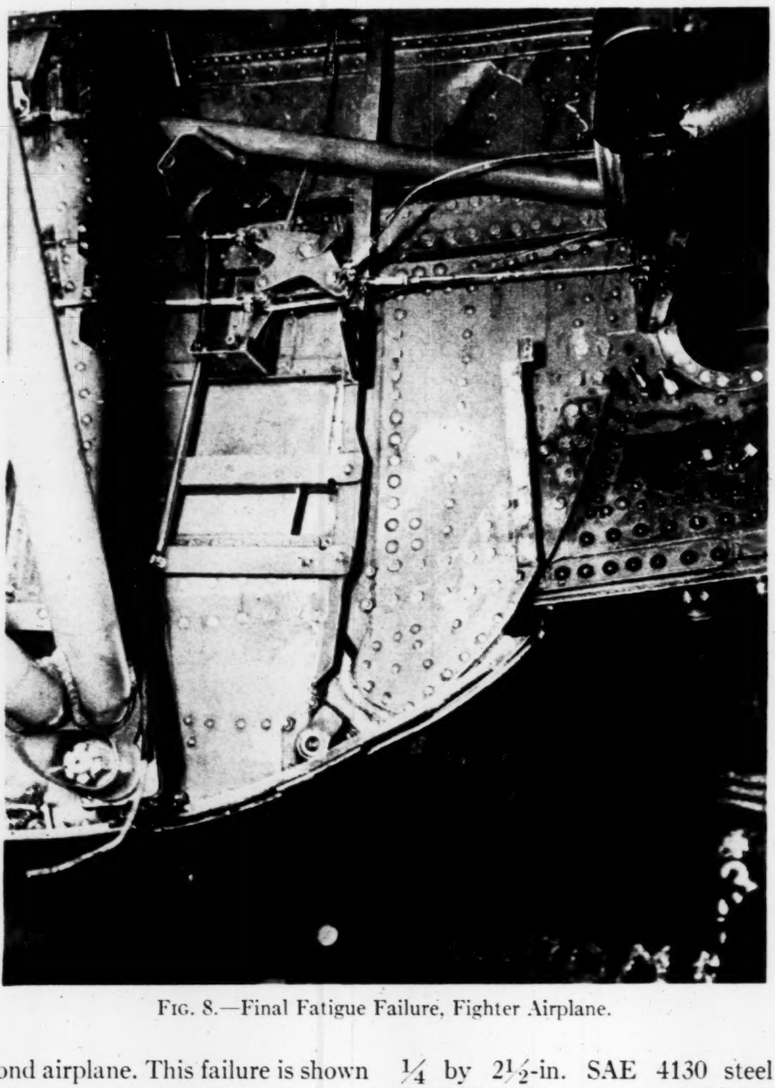


FIG. 8.—Final Fatigue Failure, Fighter Airplane.

A structural modification was then designed and installed on the airplane that had been tested first. Since it was not practicable to redesign this area of the wing to reduce the stress concentration factor, the modification was developed on the basis of reducing the stress level in the critical area. This modification consisted essentially of a ¼ by 2½-in. SAE 4130 steel strap (150,000 psi tensile strength) extending along the aft side of the vertical leg of the lower capstrip from the landing gear rib on one side to a similar location on the other side and spliced at the airplane center line, and an externally mounted $\frac{1}{4}$ by 2-in. 75S-T6 aluminum-alloy strap extending from the wing hinge to the side of the fuselage, plus the addition of numerous high-strength fastenings.

This modification was subjected to 2159 cycles of load when failure occurred through the lower capstrip and its steel reinforcement at the fuselage juncture. It is believed that this was caused by the stress concentration due to the abrupt termination of the lower skin and external reinforcement at the side of the fuselage.

Since this modification did not significantly increase the life of the wing structure, a second modification was designed and installed on the fourth test airplane. The primary changes in this modification consisted of replacing the steel reinforcement by $1\frac{1}{4}$ by $2\frac{1}{2}$-in. 75S-T6 bar, to provide a composite structure having a uniform elastic modulus, and making the external strap continuous through the fuselage. A portion of the original structure is shown in Fig. 9 while Fig. 10 shows the same area after incorporation of this modification.

This modification was considered satisfactory when it supported 9624 cycles of 100 per cent limit load plus one static test to 130 per cent limit load and one static test to 140 per cent limit load in addition to the service-imposed loads. After a repeated-load failure occurred on the port wing, the loads were interchanged and a static test to destruction was performed on the starboard wing.

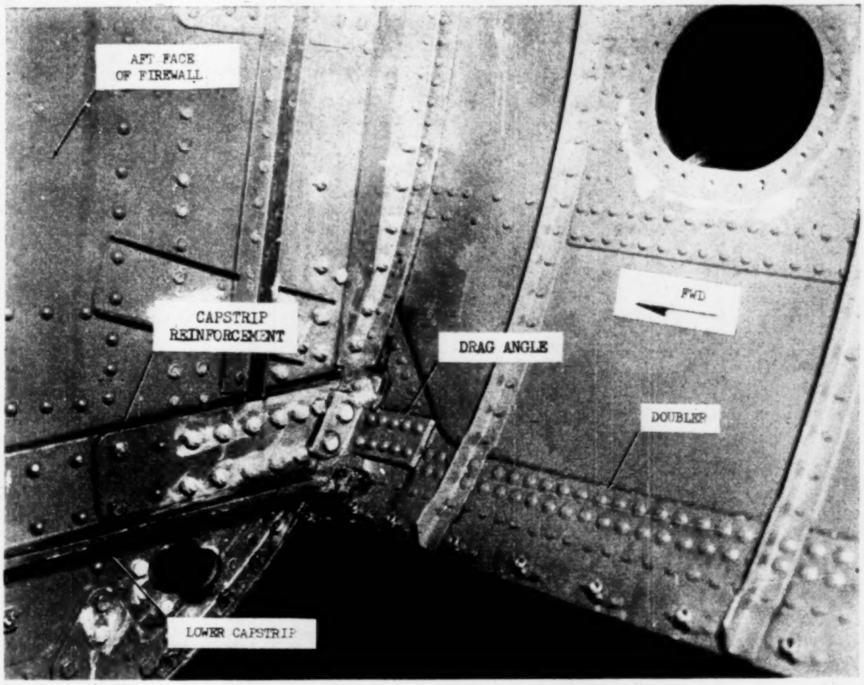


FIG. 9.—Original Structural Arrangement, Wing Center Section, Fighter Airplane, Unmodified.

in service. A third repeated-load test was then performed on another airplane with the failure occurring after 1484 cycles of limit load at the same location where the static test failure occurred on the second airplane. This failure is shown in Fig. 8.

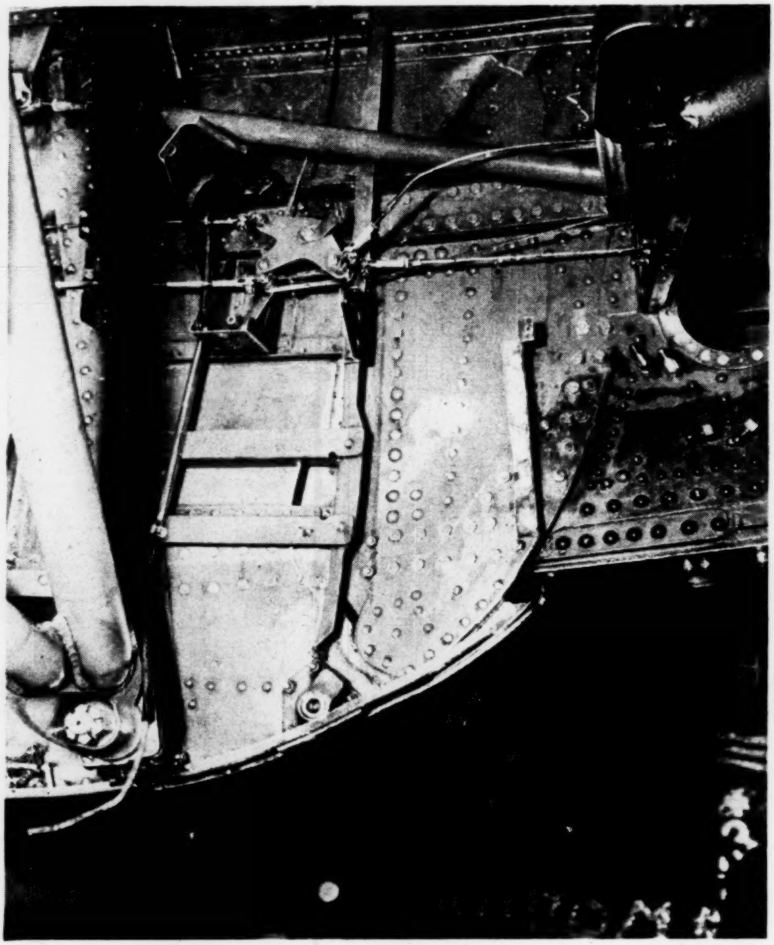


FIG. 8.—Final Fatigue Failure, Fighter Airplane.

A structural modification was then designed and installed on the airplane that had been tested first. Since it was not practicable to redesign this area of the wing to reduce the stress concentration factor, the modification was developed on the basis of reducing the stress level in the critical area. This modification consisted essentially of a ¼ by 2½-in. SAE 4130 steel strap (150,000 psi tensile strength) extending along the aft side of the vertical leg of the lower capstrip from the landing gear rib on one side to a similar location on the other side and spliced at the airplane center line, and an externally mounted ¼ by 2-in. 75S-T6 aluminum-alloy strap extending from the wing hinge to the side of the fuselage, plus the addition of numerous high-strength fastenings.

This modification was subjected to 2159 cycles of load when failure occurred through the lower capstrip and its steel reinforcement at the fuselage juncture. It is believed that this was caused by the stress concentration due to the abrupt termination of the lower skin and external reinforcement at the side of the fuselage.

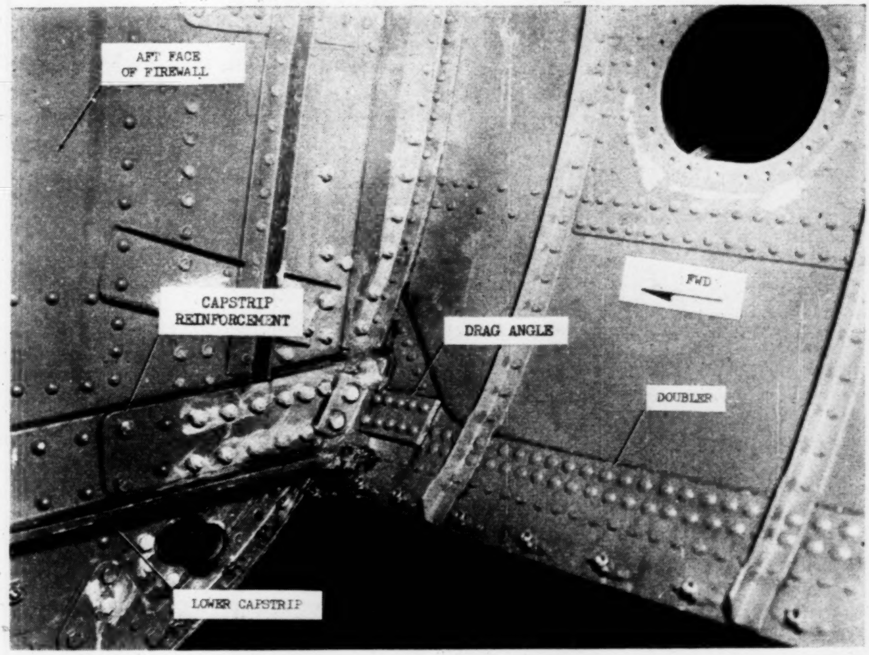


FIG. 9.—Original Structural Arrangement, Wing Center Section, Fighter Airplane, Unmodified.

Since this modification did not significantly increase the life of the wing structure, a second modification was designed and installed on the fourth test airplane. The primary changes in this modification consisted of replacing the steel reinforcement by 1¼ by 2½-in. 75S-T6 bar, to provide a composite structure having a uniform elastic modulus, and making the external strap continuous through the fuselage. A portion of the original structure is shown in Fig. 9 while Fig. 10 shows the same area after incorporation of this modification.

This modification was considered satisfactory when it supported 9624 cycles of 100 per cent limit load plus one static test to 130 per cent limit load and one static test to 140 per cent limit load in addition to the service-imposed loads. After a repeated-load failure occurred on the port wing, the loads were interchanged and a static test to destruction was performed on the starboard wing.

The failure occurred at a load of 154 per cent. Thus, although the neutral axis of the wing beam was shifted downward nearly 3 in. by the reinforcement of the lower capstrip, the static strength of the wing was not adversely affected to any appreciable extent.

During the performance of these tests, two outer wing panels also failed, one after 11,330 cycles of limit load plus four static tests and the other after 12,160 cycles of load plus three static tests. Both outer panels were practically new at the start of the tests; one had less than 100 flight hours and the other was new, having been obtained from the spare-parts supply system. It is considered that 11,000 to 12,000 cycles of limit load is representative of the life of new fighter-airplane outer wing panels. This value is within 10 per cent of the life of the reinforced center section, and therefore it is considered that a wing having an adequate fatigue life was developed during these tests.

Table III contains a brief summary of the data obtained from these tests. It will be noted that a reduction in the capstrip outer fiber stress at station 22 of approximately 12,000 psi increased the life of the structure by a factor of over 2.8.

One further comment is due concerning the effect of the spar web cracks on the fatigue life of the structure since the presence of these cracks was one of the main reasons for authorizing these tests. These cracks were observed closely during the performance of the repeated-load tests on three of the airplanes. Two of the three tests resulted in failures remote from the cracked region. The

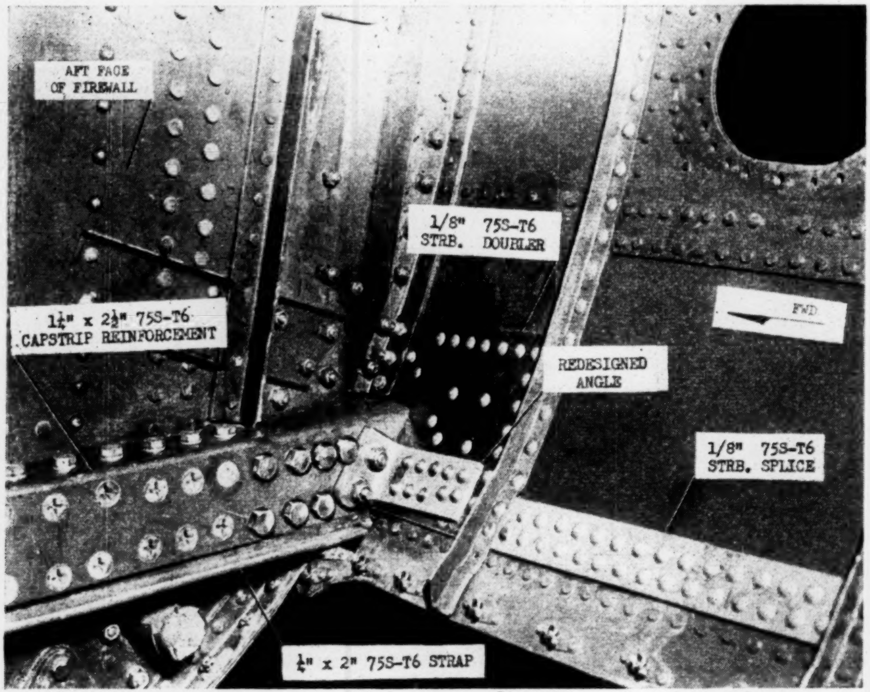


FIG. 10.—Structural Arrangement, Wing Center Section, Fighter Airplane, After Incorporation of Modification II.

third airplane failed in the region of the crack after the incorporation of the first modification; however, the failure did not extend along the crack. In no case was there any apparent lengthening of the cracks due to the repeated-load tests. One static test failure occurred along the line of the crack, but the failing load was sufficiently high (158 per cent limit load) to lead to the conclusion that the crack had no appreciable effect on the static strength of the wing. It would appear, therefore, that these cracks acted as stress relievers in this instance and did not play a primary rôle in the fatigue life of the structure.

TABLE III.—REPEATED-LOAD TESTS OF WING CENTER SECTIONS FIGHTER AIRPLANE.

Type of Outer Panel	Upper Load Level, Per Cent of Limit Load[a]	Number of Cycles		Estimated Total Number of Cycles at Failure	Measured Stress at Station 22[c]	Indicated Maximum Stress
		Test	Estimated Service[b]			
Unmodified.........	158	1 (+518)	2383	1(+2901)		
Unmodified.........	100	2003	2236	4239	35 000 psi[d]	
Unmodified.........	100	518	2383	2901		
Unmodified.........	100	1484	2800	4284		
Modification I......	100	2159 (+2003)	2236	6398	31 000 psi[e]	
Modification II.....	154	1 (+9624)	1188	1(+10 812)[h]		71 000 psi[i]
Modification II.....	100	9624	1188	10 812[h]	20 000 psi[f] 23 000 psi[g]	

[a] 100 per cent limit load = 6.3 g.
[b] Equivalent number of cycles, 100 per cent design limit load.
[c] Spanwise wing spar location measured in inches from wing centerline.
[d] Stress measured on top of horizontal leg of lower sparcap.
[e] Stress measured on lower surface of lower sparcap.
[f] Stress measured on lower sparcap reinforcement strap.
[g] Stress measured on the side of the horizontal leg of lower spar cap.
[h] Plus one cycle to 130 per cent design limit load and one cycle to 140 per cent design limit load.
[i] Calculated from measured stress of 69,200 psi at 150 per cent limit load.

Jet-Engine Fighter Airplane:

Tests to Determine S-N Curve.—A straight-wing, high-performance jet-engine fighter airplane, which is referred to as a jet fighter in the text and identified by the letters JF in the tables and figures, was tested in the final program. By a fortunate circumstance (fortunate from the viewpoint of the test engineer), it was possible to obtain ten outer wing panels for this jet fighter airplane. Static tests had disclosed these panels to be understrength and therefore unsuitable for service use. It was thought that repeated-load tests of these panels could be made to obtain an *S-N* curve, and then by means of repeated-load tests of two full-strength panels this *S-N* curve could be interpreted in terms of the fatigue life of the full-strength panels. The understrength panels differed from the full-strength panels in two ways: (1) There was a series of tapped screw holes through the skin into the vertical legs of the capstrip in the area adjacent

TABLE IV.—SUMMARY OF RESULTS OF REPEATED-LOAD TESTS OF JET FIGHTER AIRPLANE WING OUTER PANELS.

Panel	Type[c]	Upper Load Limit		Number of Cycles			$\sum \frac{n}{N}$ (Failure)	Remarks
		g	Per Cent of Limit Load	Capcrack		Outer Panel		
				Gages	Visual	Failure		
No. 1....	A	7.5	100	...	...	1 873		No strain gages installed. Crack started in rear cap angle and failure occurred in tension cap through outboard hole of hinge attachment.
No. 2....	A	6.0	80	...	4 169	No failure		Lower rear cap angle cracked in same spot as number 1 failure.
No. 3.....	A	4.5	60	11 000 to 12 000	13 000	13 861		Typical outer panel failure.
No. 4....	A	4.5	60	13 000 to 14 000	16 000	20 329		Typical outer panel failure.
No. 5....	A	6.0	80	2 500	3 405	3 647		Typical outer panel failure.
No. 6....	A		[a]	45 00 to 5 100	6 496	1 082 at 100 per cent 1 648 at 80 per cent 4 388 at 60 per cent 7 118 Total	1.283	Typical outer panel failure.
No. 7....	A		[a]	7 500	8 128	1 320 at 100 per cent 1 949 at 80 per cent 5 204 at 60 per cent 8 473 Total	1.537	Typical outer panel failure. Crack started and failure occurred in lower rear cap angle through outboard hole of hinge attachment.
No. 8....	A	7.5	100	1 500	1 741	1 861		Typical outer panel failure.
No. 9....	A		[b]	14 000	15 069	911 at 100 per cent 910 at 80 per cent 14 592 at 60 per cent 16 413 Total	1.611	Typical outer panel failure.
No. 10....	A		[b]	13 000 to 13 500	14 011	845 at 100 per cent 843 at 80 per cent 13 476 at 60 per cent 15 164 Total	1.488	Typical outer panel failure.
No. 11....	C	7.5	100	2 500	3 350	3 370		Typical outer panel failure.
No. 12....	C	4.5	60	16 000	20 830	21 029		Typical outer panel failure.

[a] Spectrum loading; 50 c at 100 per cent; 75 c at 80 per cent; 200 c at 60 per cent.
[b] Spectrum loading; 1 c at 100 per cent; 1 c at 80 per cent; 16 c at 60 per cent.
[c] A = understrength panel, C = production panel.

to the wing fold line, and (2) the doubler under the spar cap was aluminum alloy instead of 4130 steel and extended only to station 74 rather than station 86.

The static strength of both the understrength and the production (full-strength) panels had previously been determined; consequently, further static tests of these panels were not conducted under this program.

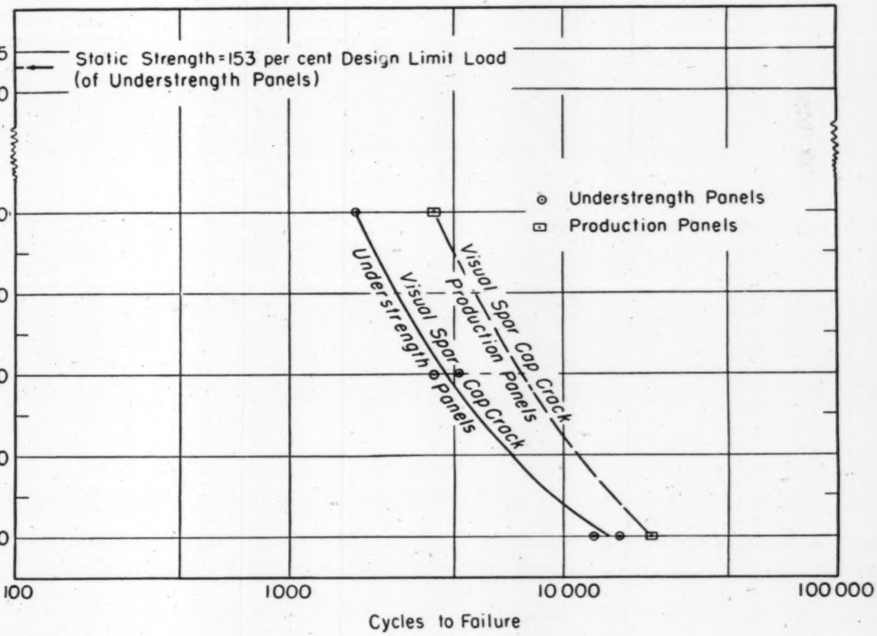


Fig. 11.—*S-N* Curve Showing Initial Spar Cap Crack of Jet Fighter Airplane Outer Wing Panels

The test method used was similar to that used for the attack airplane repeated-load tests in that the outer wing panels were tested one at a time while installed on the wing center section. The wing center section balance load on the test side was applied by a hydraulic tension jack through a fitting to the landing gear trunnion supports. The fuselage was supported at the engine mount attachment points and at the forward face of the main beam. On the dummy side, the wing center section balance load was applied through the wing main beam hinge fitting by the rolling of the center section and was measured by a tension dynamometer. The repeated-load test of panel one was conducted with a lower load level of 1 *g* (13.3 per cent limit load) and an upper load level of 7.5 *g* (100 per cent limit load). A total of six understrength panels were tested at load levels of 100, 80, and 60 per cent limit load, two panels being tested at each load level. The two production panels were tested at 100 and 60 per cent limit load and all these data are shown in Table IV. Figure 11 is a plot showing the comparison between the understrength and production panels for the initiation of a visual crack in the spar cap, while Fig.

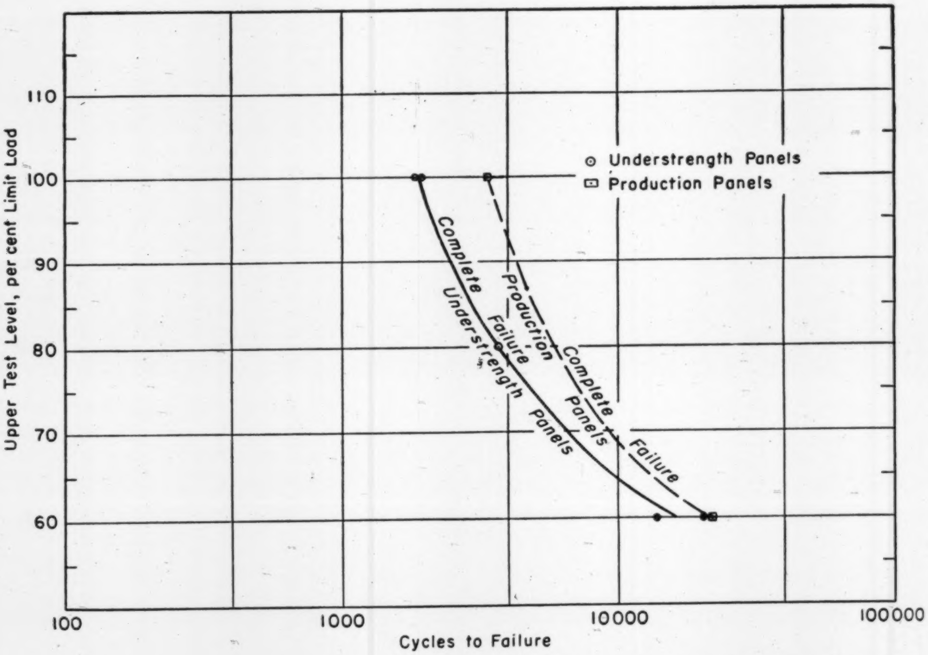
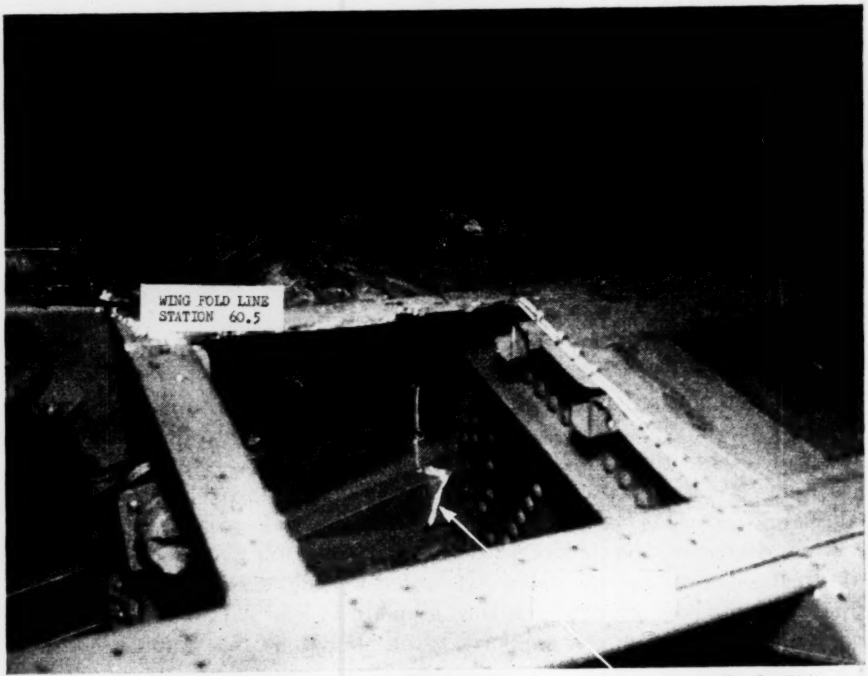


FIG. 12.—*S-N* Curve Showing Complete Failure of Jet Fighter Airplane Outer Wing Panels.



WING FOLD LINE
STATION 60.5

Failure Approx. Station 75

FIG. 13.—Typical Fatigue Failure of Jet Fighter Outer Wing Panel.

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[a] Station 75.

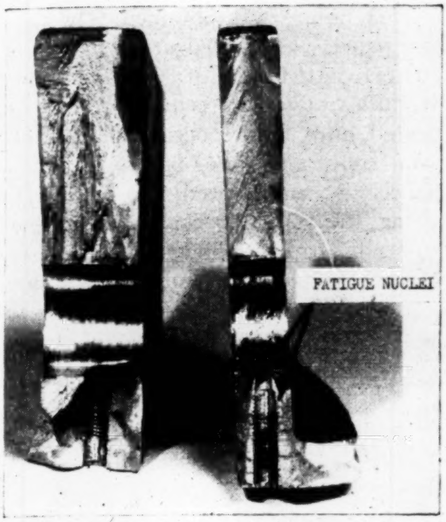

FIG. 14.—Lower Spar Cap Fatigue Failure of Jet Fighter Airplane, Station 75.

12 presents similar data for the final failure of the panels. It is of interest to note that the repeated-load failures occurred in the same general areas of the spar cap as the static test failure. The tapped screw holes in the vertical legs of the capstrip apparently were the primary contributors to failure of the panels under both static and repeated-load conditions. A view of the inboard portion of the outer wing panel is shown in Fig. 13 illustrating the typical failure of the lower spar cap and shear web. Figure 14 is a view of a lower spar cap failure showing the fatigue nuclei around the tapped hole in the aft angle of the spar cap.

The variation in strain level in the spar cap throughout the performance of the repeated-load tests for panel eleven, Table IV, is plotted in Fig. 15. This plot indicates that the initial crack started no later than 2500 cycles and probably originated near the 1-in. bolt hole through the aft capstrip since the gages nearest the bolt at station 76 showed the largest change in strain.

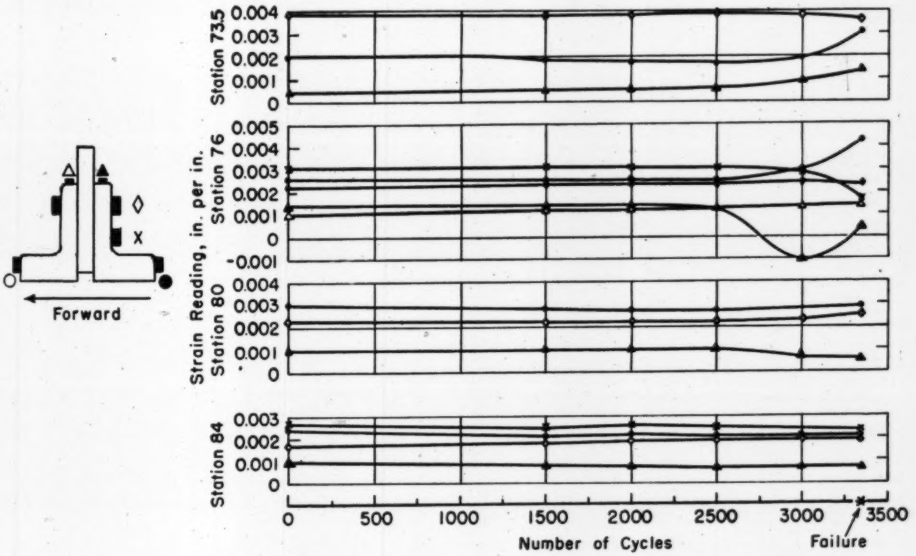

FIG. 15.—Recorded Strains in Lower Spar Cap *versus* Number of Cycles from Repeated Load Test of Jet Fighter Airplane Outer Wing Panel No. 11.

NOTE.—Failure occurred in the outer wing panel at station 75 in the vertical leg of the lower aft capstrip angle and in the spar web.

This figure also shows that the strains near the bolt were of a greater magnitude than the strains at the periphery of this capstrip.

Tests to Determine Miner's Cumulative Damage Ratio.—Four more understrength jet-fighter panels were available for testing, so it was decided to test them under spectrum loading conditions to obtain information concerning the effects of cumulative damage. Tests were chosen which would weight the spectrum loading in favor of the high loads in tests of two of the panels, and for the other two panels the loading spectrum was changed toward a predominance of lower loads. The first two panels were tested under a loading spectrum which applied 50 cycles of 100 per cent limit load, then 75 cycles of 80 per cent limit load, and then 200 cycles of 60 per cent limit load. This spectrum was repeated until a failure was obtained. The final two panels were tested using 1 cycle at 100 per cent, 1 cycle at 80 per cent, and 16 cycles at 60 per cent limit load repeated until failure occurred. Information concerning the failure of these panels is summarized in Table IV. Using the *S-N* curves for the understrength panels shown in Fig. 12, Miner's cumulative damage ratio was determined. These data are also contained in Table IV. The high values obtained for $\Sigma\frac{n}{N}$ are somewhat surprising, although the surprise is an agreeable one from the standpoint of the service employment of the airplane. It is recognized that the fairing of the *S-N* curve plays a primary rôle in the value obtained for Miner's ratio. Consequently, several curves were tried, one which emphasized minimum values and others for mean

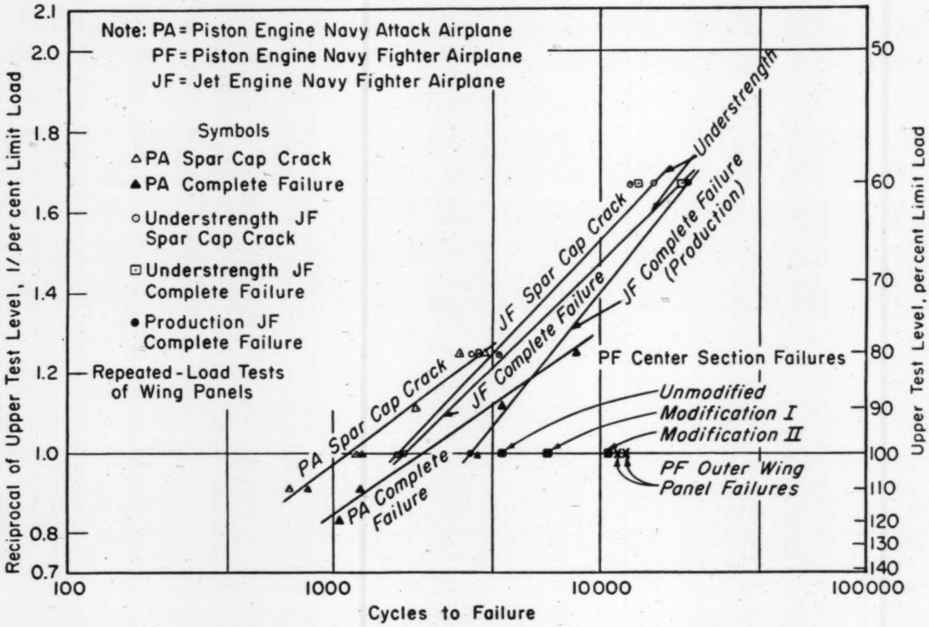

FIG. 16.—Repeated-Load Tests of Wing Panels.

and maximum values of the fatigue data. In no case, however, did the cumulative damage ratio go below 1.19, while the values quoted in Table IV are representative of the mean values. The average of these latter values is 1.48.

COMPARISON OF DATA

Figure 16 shows a composite plot of the repeated-load data obtained from all three test programs. In this figure, the ordinate is the reciprocal of the load level. This ordinate was used since it was found that the data tend to plot out as straight lines when this method was adopted. It is of interest to note that the data from the attack and jet-fighter airplanes are fairly close to being parallel when plotted in this manner. This suggests that future tests of this nature using equivalent load levels might be simplified to the extent that only check points need be obtained at two load levels to determine the location of the curve with respect to the other curves. If parallelism is not indicated, further testing would then have to be undertaken.

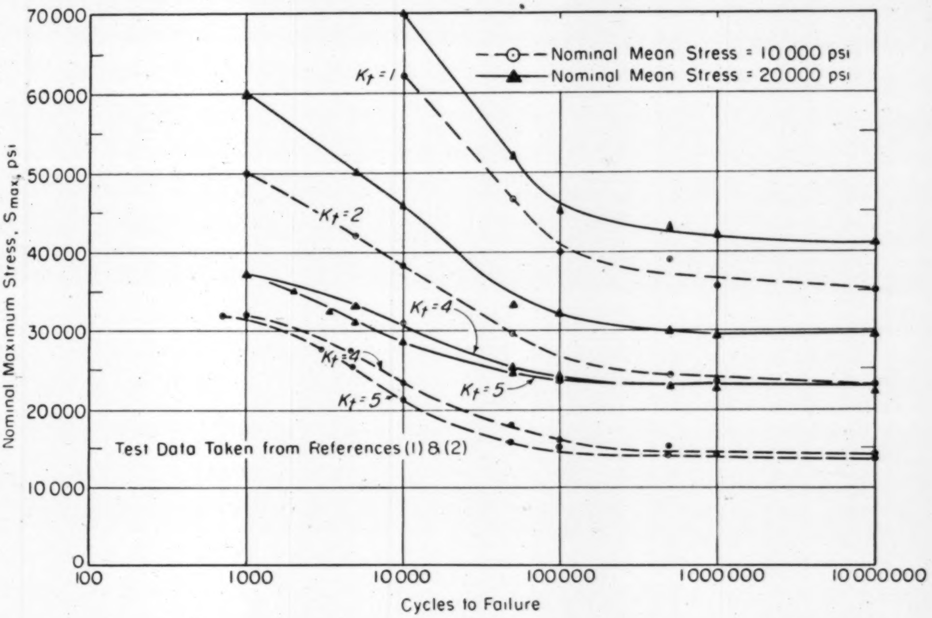

FIG. 17.—Typical *S-N* Curves. Sheet specimens with edge notches—75S-T6 aluminum alloy.

The data from these tests have been analyzed to obtain information concerning the composite stress concentration factor which would have caused these panels to fail at the number of cycles accumulated during the test of each panel. This was done by determining the maximum, minimum, and mean stress levels in the panel at the point nearest the failure where stresses were measured. In order to be conservative in these calculations, the number of cycles at which a visible crack in a primary load carrying component of the structure was first detected was used. These data are summarized in Table V. The method used in the calculation of the theoretical stress concentration

TABLE V.—COMPOSITE STRESS CONCENTRATION (K_t) AND STRENGTH REDUCTION (K_f) OBTAINED FROM WING REPEATED-LOAD TEST DATA.

Type of Aircraft	Per Cent Limit Load	Number of Cycles	Maximum Stress, psi	Minimum Stress, psi	Mean Stress, psi	K_t	K_f	Remarks
JF..........	100	1 741	42 000	5600	23 800	4.0		Understrength panels.
JF..........	80	4 169	33 600	5600	19 600	4.2		Understrength panels.
JF..........	80	3 405	33 600	5600	19 600	4.5		Understrength panels.
JF..........	60	13 000	25 200	5600	15 400	4.4	2.5	Understrength panels.
JF..........	60	16 000	25 200	5600	15 400	4.0	2.4	Understrength panels.
JF..........	100	3 350	39 500	5270	22 385	3.5		Production panels.
JF..........	60	20 830	23 700	5270	14 485	4.0	2.5	Production panels.
PA..........	110	700	39 600	5140	22 870	5.5		
PA..........	100	1 250	36 000	5140	20 570	5.3		
PA..........	90	2 000	32 400	5140	18 870	6.0		
PA..........	80	3 700	28 800	5140	16 970	5.8		
PF..........	100	4 000	35 000	5560	20 280	3.9		Unmodified panels.
PF..........	100	6 398	31 000	4920	17 960	3.9		Modification I added.
PF..........	100	10 812	30 000	4760	17 380	3.8	2.2	Modification II added.

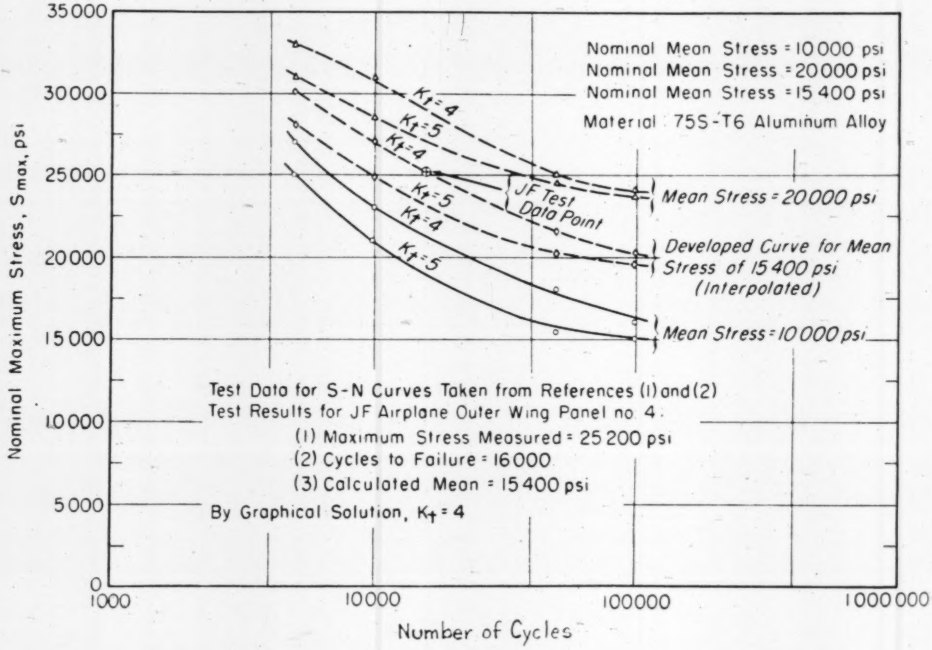

FIG. 18.—Graphical Determination of K_t for Jet Fighter Airplane Outer Wing Panel.

factor, K_t, involved the use of references (1) and (2).[2] The data from these reports were plotted in the form shown by Fig. 17 wherein the various values of K_t and mean stress level are plotted with maximum stress level as the ordinate and the fatigue life as the abscissa. By an interpolation of these data similar to that shown in Fig. 18, new curves for the various K_t values at the mean stress level present in the test specimen were determined. The failure point of the test panel was then plotted at the intersection of the maximum stress level in the panel near the point of failure and the number of cycles accumulated at failure, and the K_t value was determined by

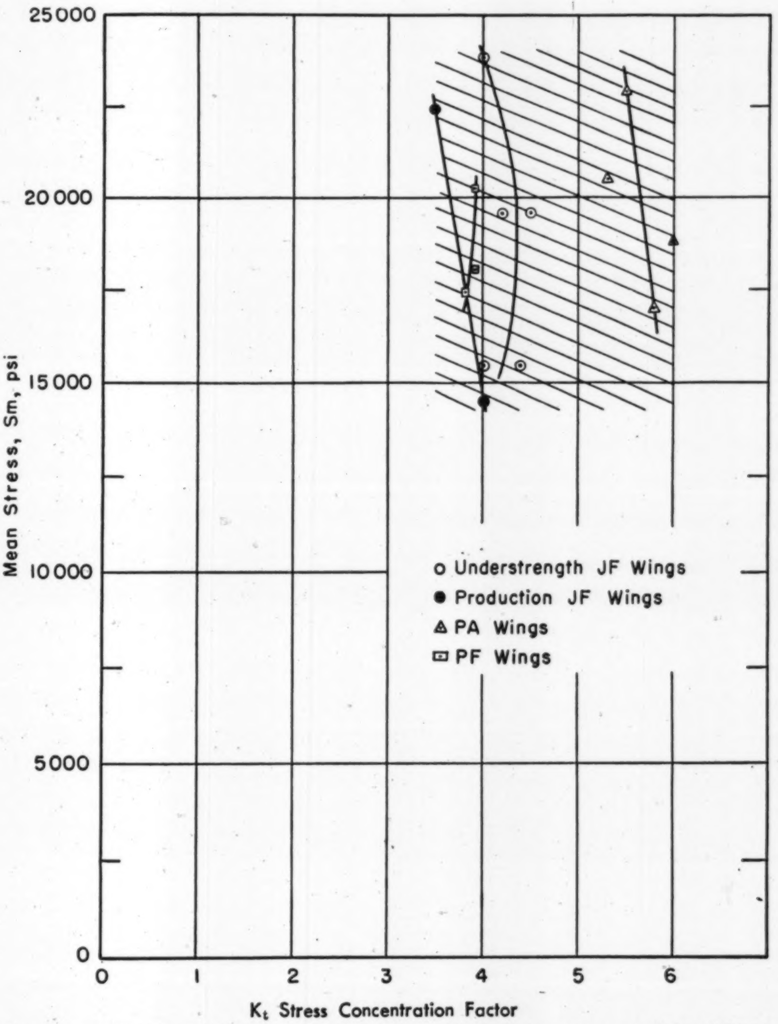

FIG. 19.—Composite Stress Concentration Factors Obtained from Repeated-Load Tests of Airplane Wings.

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[2] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 925.

interpolation between the new curves. It is recognized that this procedure does not have a high degree of accuracy for points such as those from the attack airplane which gave a K_t of greater than five. In this instance the K_t value is merely estimated by extrapolation rather than by interpolation as was done for the other K_t values.

Information concerning the strength reduction factor, K_f, was obtained where possible using the equation:

$$K_f = \frac{S_{K_1}}{S_{K_2}}$$

where:

S_{K1} = fatigue strength of the specimen with no stress concentration at n cycles,

S_{K2} = fatigue strength of the specimen with stress concentration at n cycles, and

n = cycles endured at same mean stress level.

This calculation could be made only for those data points which had fatigue lives greater than 10,000 cycles since the data for $K_t = 1$ were not available for shorter fatigue lives. These K_f values are shown in the next to last column of Table V.

The values of K_t are plotted against mean stress level in Fig. 19. Although there are not enough data available on which to base a significant conclusion, it appears that there may be a slight trend toward decreasing values of K_t with increasing mean stress levels. These data tend to agree with the data shown by Fig. 10 of reference (3) where decreasing values of K_f were noted for increasing values of alternating stress range. In reference (3) this trend was attributed to the increasing effects of plasticity associated with higher stresses as the load level was increased, and similar reasoning would appear to apply also in this case.

CONCLUSION

The plot of K_t against mean stress level in Fig. 19 emphasizes two points. First, there is a great need for additional notched specimen fatigue test data for K_t values to 6.0 particularly for the range between 100 and 10,000 cycles. This information should be obtained for extruded and bar-stock specimens as well as sheet test specimens so as to provide the designer with information applicable to the components he must use in his designs. Second, it emphasizes the need for the designer to devote increased attention to his detail design so as to reduce the composite stress concentration factor of the highly stressed areas of the airplane structure.

A final item which is also greatly needed is information on the number and frequency of moderate and high load levels experienced in service operations of the airplane. Once these latter data are obtained and further refinements are made in the theory of fatigue, it will be possible rationally to determine the service life of an aircraft and ultimately to formulate design criteria which will result in airplanes which have or exceed a certain specified fatigue life.

REFERENCES

(1) H. J. Grover, S. M. Bishop, and L. R. Jackson, "Fatigue Strengths of Aircraft Materials—Axial-Load Fatigue Tests on Notched Sheet Specimens of 24S-T3 and 75S-T6 Aluminum Alloys and of SAE 4130 Steel With Stress Concentration Factors of 2.0 and 4.0," Nat. Advisory Com. Aeronautics, Technical Note 2389, June, 1951.

(2) H. J. Grover, S. M. Bishop, and L. R. Jackson, "Fatigue Strengths of Aircraft Materials—Axial-Load Fatigue Tests on Notched Sheet Specimens of 24S-T3 and 75S-T6 Aluminum Alloys and of SAE 4130 Steel With Stress Concentration Factor of 5.0," Nat. Advisory Com. Aeronautics, Technica Note 2390, June, 1951.

(3) M. J. McGuigan, D. F. Bryan, and R. E. Whaley, "Fatigue Investigation of Full-Scale Transport-Airplane Wings—Summary of Constant-Amplitude Tests Through 1953," Nat. Advisory Com. Aeronautics, Technical Note 3190, March, 1954.

DISCUSSION

Mr. S. A. Gordon[1] (*presented in written form*).—The paper presented by Messrs. Carl and Wegeng represents one of the most significant contributions made in this country on the fatigue behavior of composite structures.

There are several points, however, that deserve some comment. The method used to determine the composite stress concentration factor, K_t is based on the assumption that *S-N* curves in Fig. 18 not only define the behavior of the monolithic specimens from which they were derived, but also define the *S-N* curve of the composite structure for which the test point was obtained. This is the only condition under which the K_t value defined by Carl and Wegeng would be independent of life. Recent tests at Battelle Memorial Inst. on a box-beam specimen, however, indicate that this is not the case. These tests show a rapid increase in the K_f values of the box-beam specimen with increasing life.

If the K_f values obtained in the authors' tests were calculated on the alternating stress only, they would be about twice the values shown in Table V. These observations would assume significant importance in design when the Miner concept for calculating cumulative damage is based on data taken from monolithic specimens rather than on data taken from composite specimens. The authors' results are within a narrow life range and are probably satisfactory for military airplanes where gust consideration is of little importance. Under these latter conditions, it would appear more advisable to develop Goodman diagrams for composite structures or for coupons designed to produce the same type of *S-N* curves.

Mr. C. R. Smith.[2]—In the first series of tests it is mentioned that the spar break was followed by a skin fracture. Is there any record of about how much time elapsed between the spar failure and the skin failure, or any observation of when the spar got so bad that it would not take any more load in the fatigue test? The cracks on the first series of panels started in the spar first.

Mr. R. A. Carl (*author*).—It could be calculated on the number of cycles that occurred between the spar crack and the cracking of the skin, and the loading rate at that time was dependent on the load level which varied from four cycles per minute at the lower load level to as low as two cycles per minute for the upper load level.

Mr. Smith.—How many cycles altogether? We are very much interested in the safety of airplanes, and have supposed that cracking in the skin would occur somewhat before final failure, skin cracks lending themselves to detection by routine inspection. Spar cracks would not be so easily detected, and it is not particularly gratifying to note the short number of cycles in some cases between first skin cracking and final failure.

Mr. Thomas J. Wegeng (*author*).—

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[1] Battelle Memorial Institute, Columbus, Ohio.

[2] Research Test Engineer, Convair, San Diego Division, San Diego, Calif.

The first indication of failure was the initial horizontal cracking of the lower spar cap. I will take one example where we were testing between the lower limit of 1*g* and an upper load level of 100 per cent limit load, and the initial crack in the spar cap occurred at 1238 cycles.

The initial skin crack occurred at 1738 cycles.

Complete failure of the panel test specimen occurred at 1889 cycles. So there was apparently a difference of about 650 cycles elapsed time between the initial crack in the spar cap and when complete failure occurred.

MR. CARL.—I might add just one thing further to that.

In inspecting the crashes which we were discussing in the paper, we mentioned that fatigue was probably a possible cause in all of the crashes; however, in the crashes we have investigated to date, we have never been able to pin it precisely on fatigue. That may be due to the fact that there are so many other possible causes that you cannot specifically pinpoint the cause as being due to fatigue.

However, there is one point which I should like to make, and that is that we have issued an inspection procedure for these airplanes which requires very frequent inspections of the area where the spar cap crack initiates.

Just recently we were able to detect this crack in one of the service airplanes. We detected this one spar cap crack which duplicated the crack that was obtained during the laboratory tests. In totalling up the number of cycles that had been imposed on the airplane during its service life (from an analysis of the airplane's log book), we were able to determine that the composite load level which the airplane would have to have been operating at in order to cause this crack to occur was approximately 80 per cent limit load, so we are on the trail of fatigue and we are getting some positive results now.

(*Authors' closure*).—Mr. Gordon's comments are appreciated and the limitations he notes in our method of determining the composite stress concentration factor are acknowledged. We make no claim that the method used by us is an optimum method for determining this factor, but rather that it is the only method available at this time by which our data could be interpreted in terms of K_t. Accordingly, we look forward to the early publication of the Battelle Memorial Inst. report mentioned in the hope that an additional tool will be made available for application to the study of fatigue of composite structures.

One might wish to know the reason we chose an edge-notched monolithic specimen as a basis for comparison in determining the values of K_t shown in Table V. The answer is very simple since this was the only type of specimen of this material for which fatigue data were available for K_t values as high as 5. Also, in determining the K_t values, we used the value of strain in the specimen as determined from the strain gage located nearest to the point of failure. Thus the strain level is correct only to the extent that it is the nearest approximation to the correct strain value that could be determined from that particular test. Accordingly, the K_t values may have errors from this source and also from the graphical method used in determining them; nevertheless, the general objective of this study, namely, the determination of the order of magnitude of the stress concentration factor present in the composite structure has been achieved through this method of analysis.

In a recent paper by Mr. J. B. Garvin entitled "Some Observations On Full Scale Aircraft Structures", presented at the National Advisory Committee for Aeronautics Conference on Some Problems of Aircraft Operation (Lewis Flight Propulsion Laboratory, Cleveland, Ohio, November 17, 18, 1954), a comparison between the fatigue characteristics of full scale aircraft structures and the fatigue of monolithic notched specimens (the latter taken from reference (1) of our paper) shows a very good agreement between 42 data points obtained from tests of P-51D wings and a curve for notched monolithic specimens having a $K_t = 4$. Over the life range where direct comparison is possible, this agreement is shown to exist from approximately 5×10^3 cycles to 5×10^6 cycles. Further extrapolation of the monolithic specimen data would indicate agreement with the full scale structure fatigue data points. This agreement indicates that the method of determining K_t values shown in our paper is a reasonable method for use at this time. Also, that the acquisition of additional monolithic specimen test data as recommended in our conclusion is desirable together with the development of additional methods of analysis and comparison similar to those discussed by Mr. Gordon.

POISSON EFFECT IN THE CHARPY TEST*

By Carl E. Hartbower[1]

In studying the transition from ductile to brittle behavior in metals, an automatic choice of performance criterion and an intuitive definition of transition temperature are likely to result in erroneous conclusions. This is particularly true in attempts to correlate data from different test specimens and may occur even in the case of comparisons with a single type of test specimen when different criteria or different definitions of transition temperature based on a single criterion are used. Stout and McGeady were among the first to bring the transition temperature dilemma into focus (**1**).[2] They contended that the choice of test specimen is far less critical to correlation of test results than is the choice of criterion used in establishing transition temperature. Since this observation was made, research findings from a number of sources have made it increasingly evident that the choice of criterion and the attending definition of transition temperature are all-important factors in analysis of test results. Thus, if an evaluation of "transition temperature" is to have significance, if there is to be any hope of interpreting the value in terms of an engineering application, it is essential that each of the various criteria and definitions in use be thoroughly understood.

It is the purpose of this paper to discuss the meaning and measurement of the Poisson effect in the V-notch and keyhole Charpy tests. It will be demonstrated that the deformation attending the fracture of a Charpy bar can be measured as either the lateral contraction occurring beneath the notch or, more easily, by the lateral expansion occurring at the compression surface of the test bar. Moreover, it will be shown that a linear relationship exists over an appreciable range of energy absorption between lateral contraction and lateral expansion and the energy required to produce fracture. Therefore, measurement of the change in lateral dimension is a duplication of effort when the energy in impact testing can be read directly from the calibrated dial of the testing machine.

THE POISSON EFFECT AS A PERFORMANCE CRITERION

Lateral contraction was described as a criterion of transition temperature by A. B. Kinzel in the 1947 Edward DeMille Campbell Memorial Lecture (**2**). Kinzel's selection of performance criterion was based on certain observations relative to service failures. Examination of service fractures showed that bright crystalline facets invariably occur at the origin of failure and often throughout the entire fracture. However, when the crack did not traverse the entire structure, fibrous areas appeared at the edges near the end of the fracture; and when-

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13–18, 1954.

[1] Chief, Welding Section, Watertown Arsenal Laboratory, Watertown, Mass.

[2] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 936.

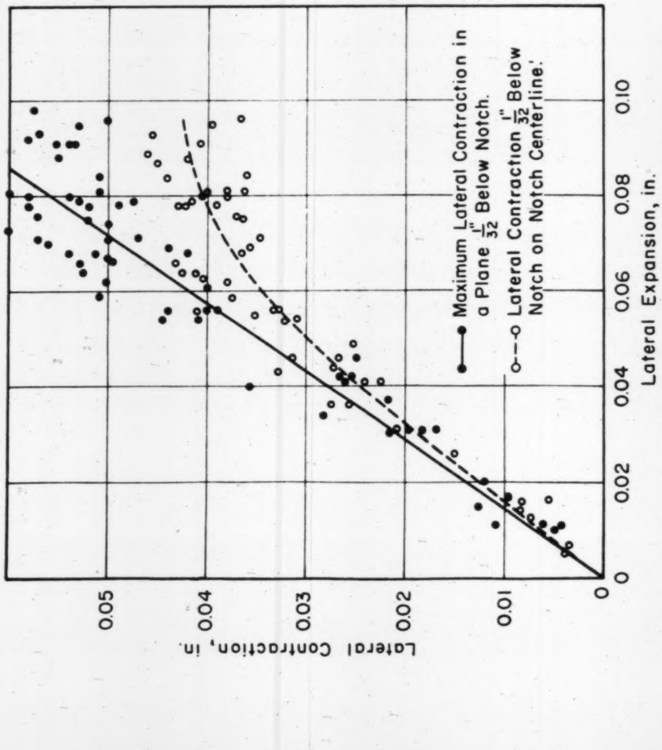

FIG. 1.—Relation Between Lateral Contraction and Expansion.

Shows the linear relationship between lateral contraction occurring at the notch and lateral expansion at the compression surface of fractured V-notch Charpy impact specimens.

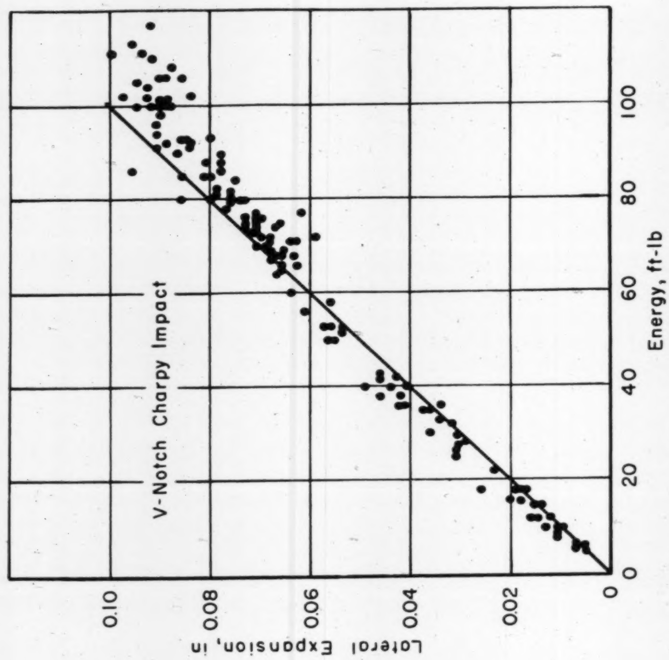

FIG. 2.—Relation Between Poisson Effect and Energy to Fracture.

Indicates an approximately linear relationship between lateral expansion and the energy absorbed in fracturing the V-notch Charpy impact specimen.

ever this occurred there was a small but perceptible reduction in cross-section of the plate. Kinzel selected this contraction in the cross-section as a criterion of material behavior. In laboratory test specimens the measurement was made adjacent to the notch using a micrometer caliper. With temperature as a variable for matching test to service, Kinzel defined transition temperature in a 3-in. wide notched bar as that temperature at which the specimen showed a 1 per cent lateral contraction parallel to the notch. The value of 1 per cent contraction was thought to correspond approximately to the deformation measured in service failure at the section near the end of cracks which stop propagating.

Since its introduction, lateral contraction has been used by a number of investigators as a performance criterion. It is generally accepted that lateral contraction is an indication of the plastic deformation that a material will undergo when subjected to the particular stress distribution of the test specimen and the rate and temperature of testing. The measurement of lateral contraction is generally treated as separate and distinct from the energy (work done in fracturing the test bar) and mode of fracture.

In an investigation of factors affecting the correlation of laboratory tests with the performance of a large structure, Hartbower and Pellini (3) investigated lateral contraction as a criterion of V-notch Charpy impact performance. A jig featuring a dial gage reading to 0.0001 in. was constructed to measure lateral contraction in a plane $\frac{1}{32}$ in. below and parallel to the apex of the V-notch. The contractions in width occurring in each side of each half of the broken specimen were measured individually and the total contraction was taken as one half the sum of the four readings. Where tears or jagged lips precluded four measurements, lateral contraction was taken as the sum of two readings. At first, readings were based on the contraction at the centerline directly under the notch. In the case of brittle fractures, this location provided a measure of maximum lateral contraction; but whenever there was appreciable ductility, the fracture path was erratic and maximum lateral contraction often occurred at a point considerably removed from the centerline of the notch. A plot of maximum lateral contraction *versus* energy revealed a simple straight-line relationship; data were plotted for measurements in over 200 Charpy bars tested over a range of temperature encompassing the transition from ductile to brittle behavior and involving a variety of metallurgical variables in two steels. The linear relationship appeared to be the same for both steels and independent of testing temperature, notch orientation, grain size, and other variations in microstructure.

Because accurate measurement of maximum lateral contraction proved to be a tedious and time-consuming operation, the laboratory technician making the measurements suggested that lateral expansion occurring on the compression side of the bar could be measured more easily. Ordinary micrometer calipers were used. It was subsequently demonstrated that not only could the measurement be made in a matter of seconds but a linear relationship existed between maximum lateral contraction and lateral expansion and energy absorbed in fracturing a Charpy bar (see Figs. 1 and 2).[3]

Knowledge of the relationship between Poisson effect and energy is useful in establishing a criterion for comparing performance in different specimens or in a single specimen under different test conditions. Consider, for example, the application where it is desired to compare transition temperature behavior in slow bend and impact using the V-notch Charpy bar. The criteria that may be used in judging performance in either case are fracture appearance, fracture strain (qualitatively evaluated by means of the Poisson effect), and energy absorbed (or work done) in fracturing the test bar. The energy absorbed in impact is obtained directly from the calibrated testing machine, whereas the work done in fracturing a slow bend specimen must be calculated from a measurement of area under the load deflection diagram.

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[3] With regard to the deviation of the plotted data from a straight line in Fig. 2, it will be demonstrated in a subsequent section of the paper that the relationship becomes nonlinear at high energy levels.

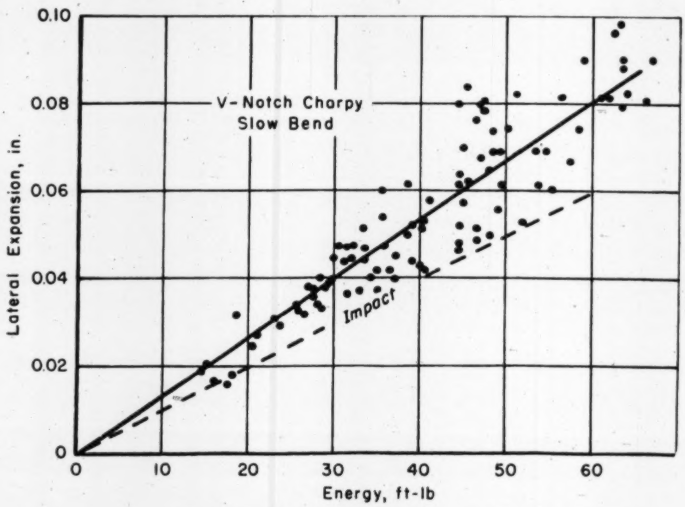

Fig. 3.—Effect of Rate of Loading.

Indicates an approximately linear relationship between lateral expansion and the work done in slow bending the V-notch Charpy bar to fracture.

TABLE I.—CHEMICAL COMPOSITION AND TENSILE PROPERTIES FOR THE MATERIALS INVOLVED IN FIGS. 3 AND 4.

Material	Chemical Analyses, per cent											
	Carbon	Manganese	Silicon	Sulfur	Phosphorus	Nickel	Copper	Chromium	Aluminum	Molybdenum	Acid Soluble Nitrogen (1:1 HCl)	Acid Insoluble Nitrogen
Aluminum-killed 1½-in. plate	0.20	0.58	0.21	0.27	0.018	0.074	0.13	0.047	0.04	0.007	0.006	Nil
Silicon-killed 1-in. plate	0.23	0.54	0.12	0.041	0.012	0.048	0.044	0.055	0.01	0.005	0.005	Nil
Rimmed ¾-in. plate	0.19	0.35	0.01	0.028	0.018	0.014	0.33	0.065	0.01	0.029	0.007	0.003

Tensile Properties (after Normalizing at 1650 F for 1½ hr)

Material	Yield Strength, 0.2 per cent Offset, psi	Tensile Strength, psi	Elongation in 2 in., per cent	Reduction in Area, per cent
Aluminum-killed steel	42 100	62 200	39.5	67.2
Silicon-killed steel	39 600	64 000	38.0	63.8
Rimmed steel	41 200	64 000	36.5	58.0

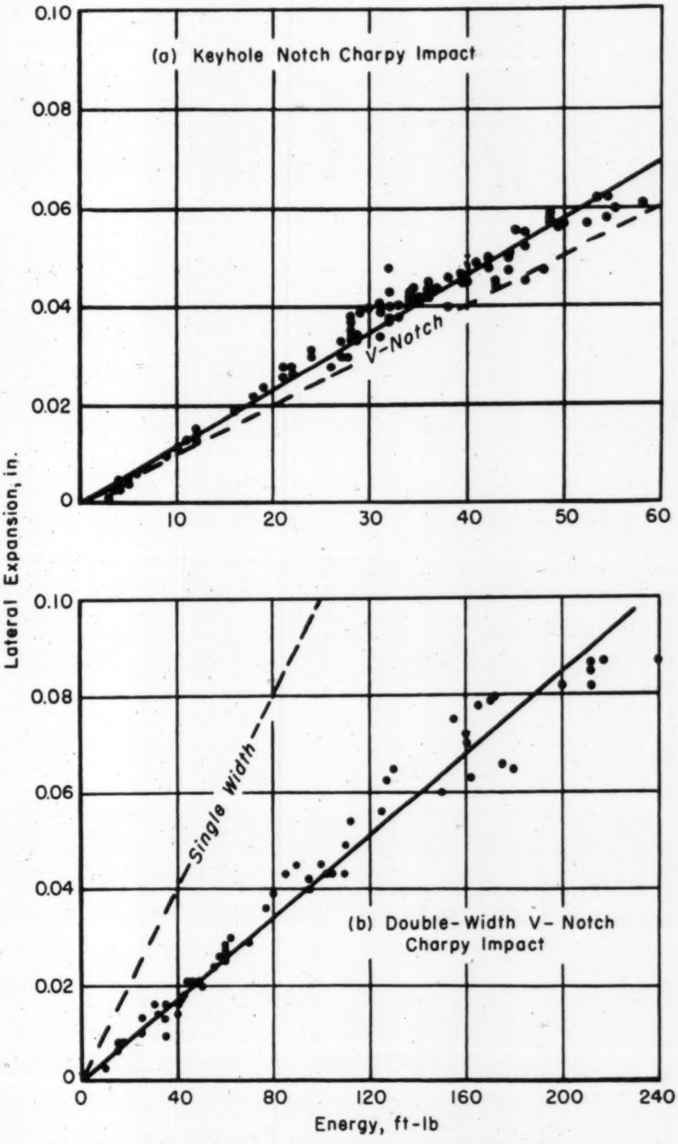

FIG. 4.—Effect of Notch Acuity and Cross-Section Dimension.

Indicates a linear relationship to hold for both the keyhole Charpy and the double-width V-notch Charpy impact specimens.

If a linear relationship exists between Poisson effect and work done in fracturing a slow bend specimen, the measurement of lateral expansion would obviate the more tedious measurement of area in the slow bend test. Although lateral expansion measurements plotted against work done in fracturing slow bend specimens (Fig. 3) resulted in a considerable scatter, a line faired through the data appeared to be a reasonable approximation. Data from three steels are contained in Fig. 3; the steels are similar in chemical composition but represent a variety of mill practices. Chemical analyses and tensile properties of the steels are reported in Table I.

With a linear relationship between Poisson effect and work done in slow bend and impact, it is possible to compare transition temperature behavior based upon an energy level in impact and a corresponding deformation level in slow bend. Thus, comparisons between transition temperatures corresponding to 15 ft-lb in impact and 3.8 per cent lateral expansion in slow bend are based upon a single performance criterion.

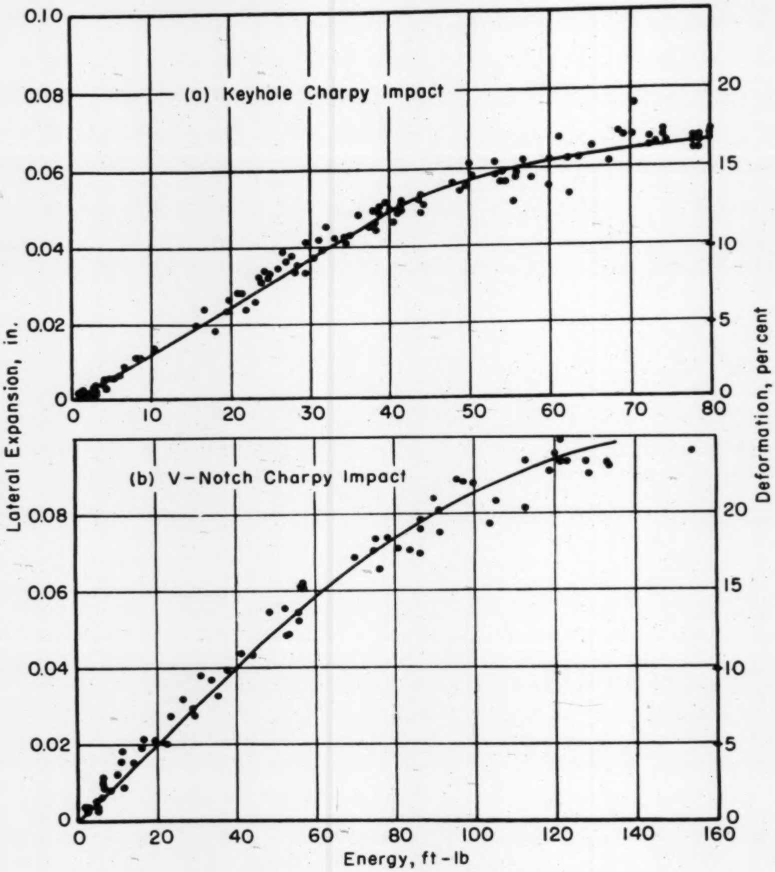

FIG. 5.—Extent of the Linear Relationship.

Presents data from 12 steels with carbon contents ranging from 0.04 to 0.45 per cent and manganese from 0.43 to 1.05 per cent. The data indicate a straight line to be a good approximation for deformations up to about 12 per cent for both the keyhole and the V-notch Charpy impact specimens.

TABLE II.—CHEMICAL COMPOSITION OF CARBON-MANGANESE STEELS.

Carbon	Manganese
0.04	0.43
0.04	0.56
0.04	0.74
0.04	0.98
0.09	0.43
0.15	0.49
0.21	0.47
0.20	0.69
0.20	0.92
0.32	0.48
0.31	1.05
0.45	0.43

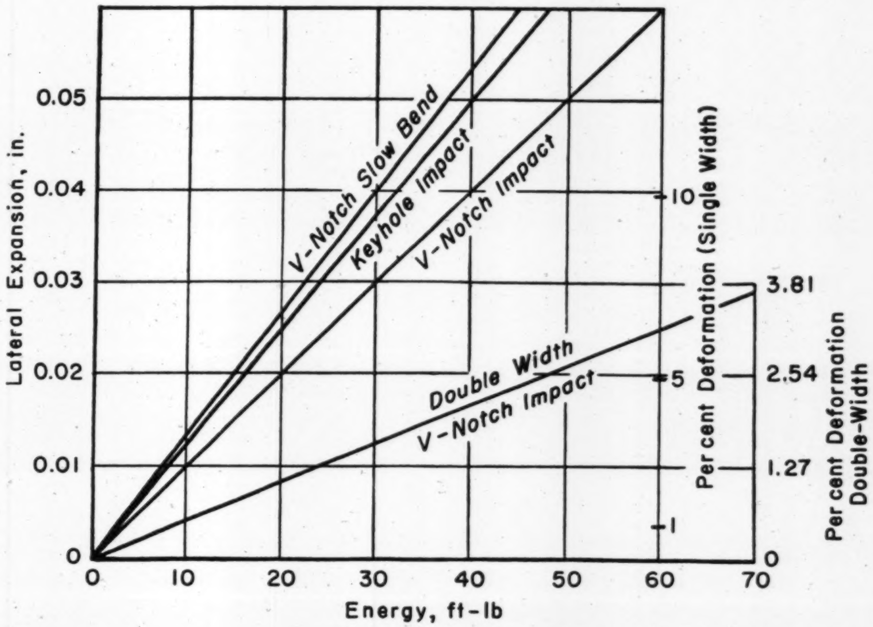

FIG. 6.—Relation Between Energy and Poisson Effect in Fracturing Charpy Specimens.

KEYHOLE, V-NOTCH, AND DOUBLE-WIDTH V-NOTCH CHARPY

A plot of lateral expansion *versus* energy absorbed in V-notch Charpy impact for the three steels of Table I indicated a straight line of approximately the same slope as for Fig. 2. Keyhole Charpy impact data were also obtained on the steels listed in Table I. Again the plot of lateral expansion *versus* energy indicated (Fig. 4) a straight line, but the slope was somewhat greater than that obtained with the V-notched specimen; thus the keyhole Charpy specimen was indicated to require less energy to produce a given fracture strain than the V-notched specimen. Poisson effect was also measured in a double-width V-notch Charpy impact specimen. A plot of lateral expansion *versus* energy absorbed in fracturing the double-width specimen again indicated a linear relationship. A marked difference was noted, however, in the amount of energy corresponding to a given fracture strain: 15 ft-lb was attended by a 3.8 per cent lateral expansion in the single-width V-notch Charpy impact specimen, whereas approximately 70 ft-lb were required to produce the same deformation in the double-width specimen. Conversely, with 15 ft-lb of energy absorbed in fracturing the specimen, the single-width bar deformed 3.8 per cent, whereas the double-width bar deformed less than 1 per cent.

EXTENT OF THE LINEAR RELATIONSHIP

Additional data were obtained to test the validity of representing the plot of lateral expansion *versus* energy as a straight line (Fig. 5). Twelve steels were investigated with carbon and manganese contents ranging from 0.04 to 0.45 per cent carbon and from 0.43 to 1.05 per cent manganese (Table II).[4] The materials were prepared in laboratory heats, deoxidized with silicon and aluminum to simulate commercial fine grain practice, forged to $\frac{5}{8}$-in. square bar stock, and normalized at 1700 F. Lateral expansion was measured in approximately eight specimens of each composition and each type of notch. The specimens were fractured at temperatures ranging from approximately −100 to +100 C. Data from partially fractured specimens which absorbed energies near the capacity of the test machine were discarded.

A straight line appears to be a good approximation for the range of 0 to 50 ft-lb in the case of the V-notch Charpy impact specimen and for the range of 0 to 40 ft-lb in the case of the keyhole Charpy impact specimen.

SUMMARY

A linear relationship exists between Poisson effect and the energy to fracture pearlitic steel Charpy bars. The linear relationship extends over a range of 0 to 50 ft-lb in the case of the V-notch Charpy impact specimen and over a range of 0 to 40 ft-lb in the case of the keyhole Charpy impact specimen.

The relationship is independent of such metallurgical variables as chemical composition and heat treatment, and is independent of testing temperature.

The existence of the linear relationship between the Poisson effect and energy obviates the measurement of lateral expansion or contraction in the Charpy impact test since energy may be read directly from the calibrated testing machine. If, however, it is desired to compare tests which differ in physical dimension, notch acuity, or rate of loading, a plot of lateral expansion *versus* work done in producing fracture provides a measure of the relative resistance to deformation in the tests (Fig. 6).

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[4] Data were obtained from specimens prepared for an unpublished study sponsored by the Development and Research Division, International Nickel Co., In., New York, N. Y.

REFERENCES

(1) R. D. Stout and L. J. McGeady, "The Meaning and Measurement of Transition Temperature," *The Welding Journal*, Vol. 27, No. 6, June, 1948. pp. 299–s.

(2) A. B. Kinzel, "Ductility of Steels for Welded Structures," *The Welding Journal*, Vol. 27 No. 5, May, 1948, pp. 217–s.

(3) C. E. Hartbower and W. S. Pellini, "Mechanical and Material Variables Affecting Correlation," *The Welding Journal*, Vol. 29, No. 7, July, 1950, pp. 348–s.

DISCUSSION

MR. R. H. FRAZIER[1] (*by letter*).—Mr. Hartbower is to be congratulated for making an interesting observation with respect to the lateral expansion in the Charpy test. The lateral expansion is much easier to measure than lateral contraction. The author has clearly shown that testing temperature, carbon and manganese content, and deoxidation have no apparent effect on the relationship of lateral expansion and energy value of a given type of test. In the summary, heat treatment is also included in the list of ineffective variables. This might be true as long as there is no major change in microstructure. V-notch Charpy impact

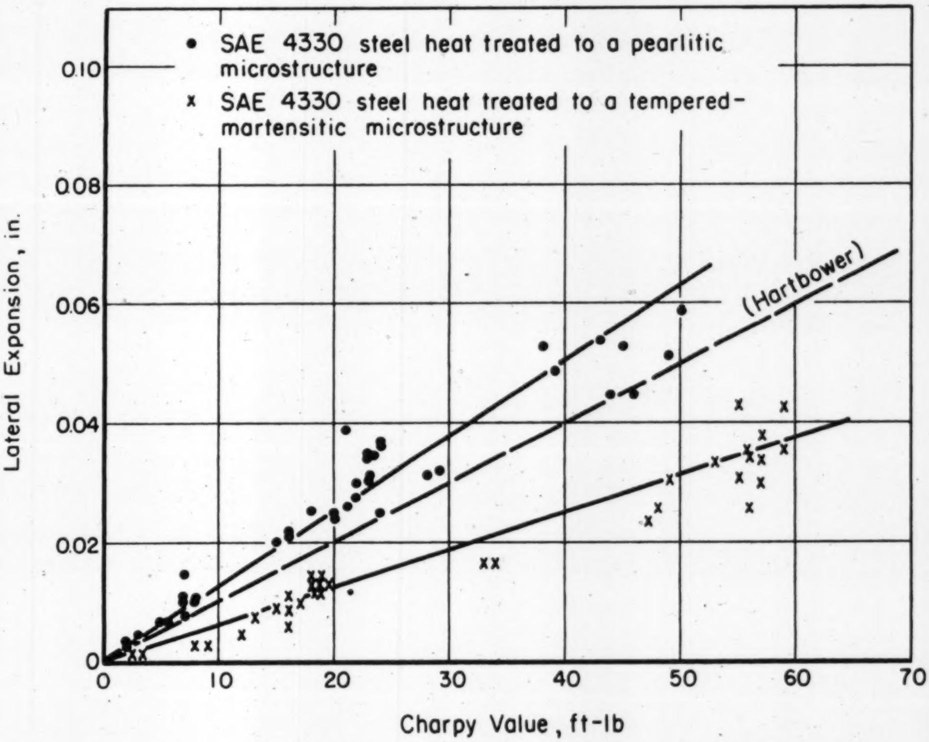

FIG. 7.—Effect of Microstructure on Lateral Expansion—Charpy Value Relationship.

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[1] Assistant Chief, Division of Ferrous Metallurgy, Battelle Memorial Inst., Columbus, Ohio.

tests made at Battelle Memorial Inst. on SAE 4330 steel heat treated to a pearlitic structure and to a tempered martensitic structure revealed some interesting results. The lateral expansion was measured on Charpy specimens tested at various temperatures and heat treated to the two types of microstructure. The results of these tests are shown in the accompanying Fig. 7. The energy requirements for the same lateral expansion is much greater for the tempered-martensitic steels than it is for the pearlitic steels. Therefore, the metallurgical variable of heat treatment should be left out of the list of ineffective variables.

The lateral expansion was measured on a number of keyhole Charpy specimens from semikilled steels of different carbon and manganese contents and tested at various temperatures. These measurements are plotted in Fig. 8 against the Charpy value. The dashed line is the relationship found by Mr. Hartbower. Our values were lower for the same lateral expansion than those determined by the author; however, this discrepancy is probably not significant.

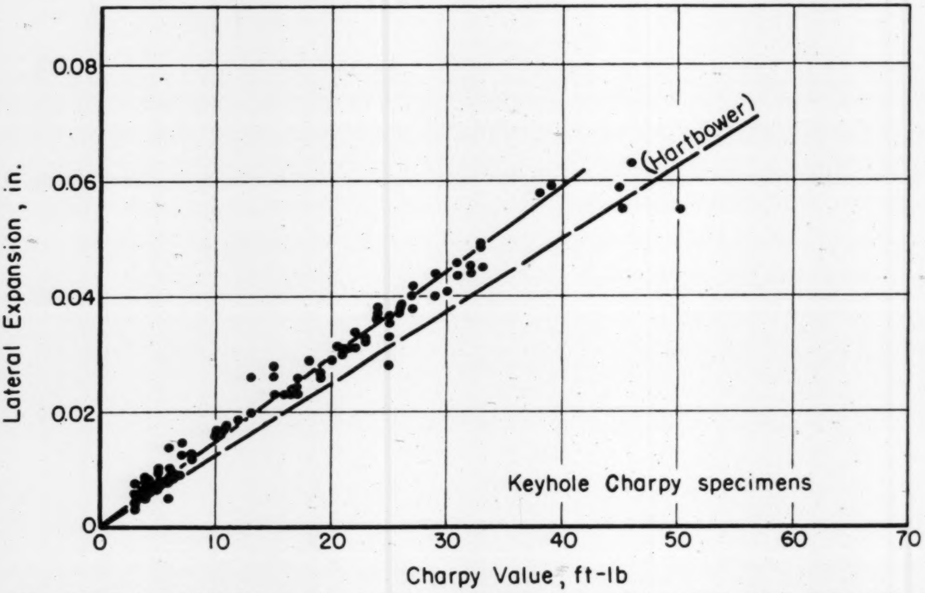

FIG. 8.—Relationship Between Lateral Expansion and Charpy Value of Hot-Rolled Semikilled Steels.

MR. CARL E. HARTBOWER (*author*).—The additional data provided by Mr. Frazer are very much appreciated. The author, at the time of reporting, was aware of the difference in slope in the case of quenched-and-tempered steel but had insufficient data to present the information; therefore, all remarks were limited to pearlitic steel. Mr. Frazer's data on a single steel in two conditions of heat treatment, one martensitic and the other pearlitic, show conclusively that when heat treatment produces a tempered martensitic-structure, the relationship between lateral expansion and Charpy impact value is decidedly changed; that is, for a given amount of energy absorbed in fracturing the Charpy bar, appreciably less deformation occurs in the case of the quenched-and-tempered martensitic structure than in the case of a pearlitic structure.

EFFECT OF SPECIMEN SIZE ON NOTCHED BAR IMPACT PROPERTIES OF QUENCHED-AND-TEMPERED STEELS*

By Harry Schwartzbart[1] and J. P. Sheehan[2]

Synopsis

The impact properties of 8600 steel at four carbon levels, 5140, and 4140, quenched and tempered at temperatures from 400 to 1200 F, have been determined, using three sizes of impact specimens geometrically similar except for notch radius which was held constant. The linear scale factors of the specimen sizes investigated were 1:2:3.3 with the standard Charpy specimen having the scale factor of 2.

The conclusions are as follows:

1. Maximum impact energy per unit fracture area (area under the notch) is relatively independent of specimen size at tempering temperatures from 400 F to 700–800 F, but is dependent on specimen size at tempering temperatures between 700–800 F and 1200 F. In this region, maximum impact strength is higher the larger the specimen dimensions.
2. Maximum impact energy per unit volume decreases with increasing specimen size over the entire range of tempering temperatures investigated.
3. A distinct size effect is exhibited in transition temperature; the transition temperatures of the small specimens were considerably lower than those of the standard size specimens, which were in turn generally lower than those of the large specimens, especially at high hardnesses.
4. For the 8600 series of steel, transition temperature increases with carbon content.

One question of paramount importance to design engineers is the amount of error involved in applying the data from testing small size specimens to the design of a large structure such as a ship or bridge. Many investigations have demonstrated that the strength of a metal is not independent of the size of specimen used to determine the strength. The issue is further complicated in the case of steel structures by the presence of the transition from tough to brittle behavior as the test or service temperature is lowered. This requires, then, that we know not only the effect of specimen size on strength at a given temperature, but that we know also the effect of specimen size on transition temperature. This subject has been considered to some extent in the literature, and some limited data have been reported.

The subject of size effects in fracturing has been reviewed in a recent paper by Irwin (**1**)[3] who has contributed much toward our understanding of the dynamics of the fracturing process. Among the investigations which have demonstrated such size effects, the following are significant: Stanton and Batson (2) on scaled impact tests of several steels in several conditions of velocity and notch geometry; Docherty (3) and Shearin, Ruark, and Trimble (4) on slow bending of notched bars of various ferrous and non-ferrous materials; Brown, Lubahn, and Ebert (5), Gensamer (6), and Fried and Sachs (7) on notched tension bars; Davidenkov, Shevandin, and Wittmann (8) on impact and slow bending, and impact tension; MacGregor and Grossman (9) on simple bending of circular disks supported around the circumference and loaded at the center; and Parker (10) on tension tests of wide plates containing holes.

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13–18, 1954.

[1] Alloy Engineering and Casting Co., Champaign, Ill.; Formerly Armour Research Foundation, Chicago, Ill.

[2] Armour Research Foundation, Chicago, Ill.

[3] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 951.

Fracture size effects were generally observed in these investigations. Some of the investigations (2, 8) indicated a limiting section size below which a marked size effect was observed and above which the size effect was negligible. Stanton and Batson (2) found from their notched impact bend tests that toughness increased with size if the impact energy was referred to unit fracture area under the notch; the reverse was true if the impact energy was referred to unit volume of the impact specimens.

Most of these investigations did not include determinations of transition temperature or the effect of temperature as a variable. Those that did (8, 9, 10, 11) generally found that the transition temperature was higher for large specimens than for small specimens. Mac Gregor and Grossman (9) found, however, that the effect of size on transition temperature was trivial over a scale change of 6 to 1.

The purpose of the present work was to study the effect of proportionally varying the dimensions of the impact specimen on impact properties and, specifically, on transition temperatures.

TABLE I.—CHEMICAL ANALYSES, NORMALIZING AND AUSTENITIZING TEMPERATURES.

Heat	Nominal Grade	Normalizing and Austenitizing Temperature, deg Fahr	Carbon	Manganese	Phosphorus	Sulfur	Silicon	Nickel	Chromium	Molybdenum
3895...........	8620	1650	0.24	0.79	0.017	0.025	0.15	0.59	0.66	0.18
3898...........	8630	1575	0.33	0.81	0.025	0.017	0.21	0.63	0.63	0.16
3899...........	8640	1550	0.42	0.81	0.021	0.016	0.16	0.71	0.50	0.18
3900...........	8655	1475	0.53	0.88	0.024	0.016	0.23	0.79	0.52	0.20
3905...........	5140	1550	0.42	0.84	0.025	0.025	0.17	...	0.96	...
3930...........	4140	1550	0.40	0.95	0.025	0.039	0.21	...	1.05	0.22

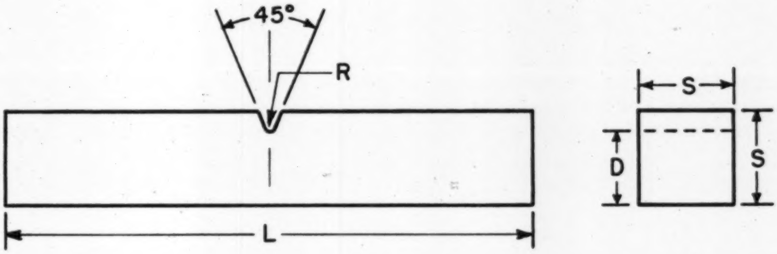
EXPERIMENTAL PROCEDURE

The Charpy impact properties of six steels were investigated in the quenched-and-tempered condition. The steels included SAE 4140, 5140, and 8600 containing 0.20, 0.30, 0.40 or 0.55 per cent carbon; chemical analyses are presented in Table I.

The heats were made in a 500-lb laboratory induction furnace with 2 lb of aluminum per ton used for deoxidation. Sixty-five pound ingots were poured from each heat. The ingots were forged to flat bars from which the impact specimens were cut in the longitudinal direction. To prepare the steel for machining, the forged bars were normalized at the temperatures listed in Table I, then heated for 1 hr at 1200 F and air cooled.

Specimen blanks were cut from the forged flats, quenched and tempered, then finish machined. Heat treatment consisted of 30 min at the austenitizing temperatures listed in Table I, oil quenching, and tempering for 1 hr over a range of temperatures from 400 to 1200 F, followed by water quenching.

Three sizes of impact specimens, geometrically scaled in every dimension with the exception of the notch radius, were tested on a Baldwin-Sonntag Universal Impact Machine. The linear scale factors were 1:2:3.3 with the standard Charpy specimen dimensions having the scale factor of 2, and the other two specimens being subsize and oversize. Specimen dimensions are presented in Fig. 1. The energy and velocity of the striking head of the impact machine were not scaled proportionally, but were varied as shown in Fig. 1. The supporting span of the impact specimens was scaled proportionally.



Type	Linear Scale Factor	L, in.	S, in.	D, in.	R, in.	Volume, cu in.	$S \times D$ Fracture Area, sq in.	Capacity of Impact Machine, ft-lb	Hammer Velocity at Impact, ft per sec
Small	1	1.083	0.197	0.158	0.010	0.042	0.0311	25	11
Standard	2	2.165	0.394	0.315	0.010	0.335	0.124	120 and 240	17
Large	3.3	3.544	0.644	0.515	0.010	1.47	0.332	375	17

FIG. 1.—Specimen Dimensions for Size Effect Study.

The decision not to vary the notch radius was arbitrary. Actually, a true investigation of size effect requires, among other things, that all corresponding points in specimens of various dimensions are subjected to exactly the same stress and strain states. Since it was felt that this condition could not be achieved in impact bend testing of notched bars, this investigation does not presume to be an investigation of a true size effect, but in a stricter sense, as indicated by the title of the paper, an investigation of the effect of specimen size on impact properties. It should be kept in mind, then, when the expression "size effect" is encountered in subsequent discussion in this paper, it is used for convenience to denote variation of properties with specimen dimensions within the scope of the present investigation.

Specimens were broken over a range of testing temperatures from −320 F to above the energy transition temperature or to a temperature equal to the tempering temperature. The fracture surfaces were rated by comparison with a set of standards as to the percentage of shiny, crystalline surface which is characteristic of brittle fracture.

Broken impact specimens which had

been tempered at 400 F were sectioned and examined metallographically to determine if 100 per cent martensite had been obtained on quenching. The large specimen of 8620 steel was found to have 15 to 20 per cent of nonmartensitic transformation products. The standard size specimen had no more than 1 per cent of nonmartensitic transformation products and the small specimen was 100 per cent martensitic before tempering. The large specimens of the other steels had at least 99 per cent martensite before tempering.

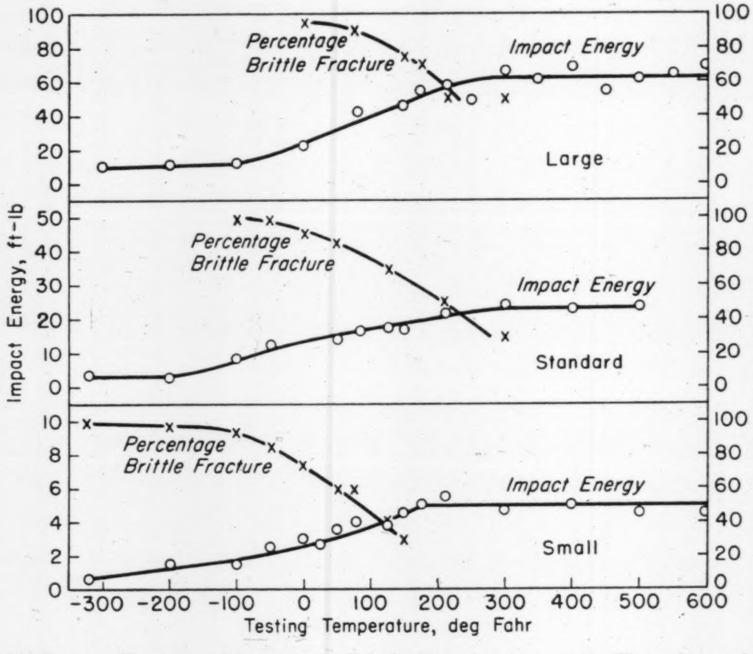


FIG. 2.—Impact Energy and Percentage Brittle Fracture Curves for Three Sizes of 5140 Steel Tempered at 800 F.

EXPERIMENTAL RESULTS AND DISCUSSION

Impact energy and percentage brittle fracture have been plotted against testing temperature; examples are presented in Fig. 2. These curves are for the three sizes of SAE 5140 tempered at 800 F. It can be seen that the impact energy rises steadily with testing temperature through the transition zone and reaches a value which remains essentially constant as the testing temperature is further increased. This permits the use of the temperature at 80 per cent of the maximum energy as one criterion of transition temperature at the high energy levels. The temperature at 90 per cent brittle fracture is also used as a criterion of transition temperature in the region of brittle behavior. A complete discussion of the various fracture and energy transition criteria and the reasons for the selection of those used here was presented in a previous paper (12). (Points are plotted only for specimens in the transition zone so as to determine the temperature of 90 per cent brittle fracture.) Both these criteria of transition temperature are

TABLE II.—TRANSITION ENERGIES AND TEMPERATURES.

Nominal Grade	Tempering Temperature, deg Fahr	Specimen Size	80 per cent Maximum Energy, ft-lb	80 per cent Maximum Energy per Unit Area Under the Notch, ft-lb per sq in.	80 per cent Maximum Energy per unit Volume, ft-lb per cu in.	Transition Temperature, deg Fahr	
						80 per cent Maximum Energy Criterion	90 per cent Brittle Fracture Criterion
		HEAT 3895					
8620 (0.24% C)	400	Small	4.8	154	114	−125	−210
		Standard	22	181	67	−65	−125
		Large	83	250	56	75	−45
	500	Small	4.0	129	95	−100	−150
		Standard	21	169	63	−30	−80
		Large	75	226	51	85	−20
	600	Small	4.8	154	114	15	−115
		Standard	16	129	48	−45	−20
		Large	77	232	52	165	10
	700	Small	4.8	154	114	−25	−140
		Standard	21	169	63	35	−20
		Large	82	247	56	140	20
	800	Small	6.4	206	152	−55	−175
		Standard	25	206	76	70	−65
		Large	96	289	65	75	−15
	1000	Small	8.8	283	210	−120	−300
		Standard	48	387	143	−85	−150
		Large	176	530	120	−25	−140
	1200	Small	12.8	412	305	−135	−320
		Standard	80	645	239	−70	...
		Large	234	705	159	−110	−200
		HEAT 3898					
8630 (0.33% C)	400	Small	4.2	135	100	−65	−250
		Standard	20	161	60	−20	−125
		Large	48	145	33	−95	−95
	500	Small	3.8	122	90	10	−180
		Standard	19	157	58	−40	−105
		Large	40	120	27	−10	25
	600	Small	3.8	122	90	125	−130
		Standard	17	141	52	130	35
		Large	40	120	27	60	55
	700	Small	4.5	145	107	95	−110
		Standard	20	161	60	75	20
		Large	36	108	24	−25	35
	800	Small	5.6	180	133	25	−200
		Standard	25	206	75	120	−35
		Large	48	145	33	−160	−60
	1000	Small	8.5	273	202	−105	−305
		Standard	45	367	134	−25	−185
		Large	137	413	93	−45	−195
	1200	Small	11	360	267	−135	−320
		Standard	64	516	191	−125	−200
		Large	210	633	143	−130	−230

[Continued on Pages 944 and 945.]

TABLE II.—*Continued*

Nominal Grade	Tempering Temperature, deg Fahr	Specimen Size	80 per cent Maximum Energy, ft-lb	80 per cent Maximum Energy per Unit Area Under the Notch, ft-lb per sq in.	80 per cent Maximum Energy per Unit Volume, ft-lb per cu in.	Transition Temperature, deg Fahr	
						80 per cent Maximum Energy Criterion	90 per cent Brittle Fracture Criterion
HEAT 3899							
8640 (0.42% C)	400	Small	2.7	87	64	−5	−95
		Standard	13	105	39	−10	45
		Large	42	126	29	100	100
	500	Small	2.9	93	69	40	−60
		Standard	14	117	43	75	40
		Large	35	105	24	−35	60
	600	Small	2.9	93	69	150	−5
		Standard	13	105	39	110	60
		Large	35	105	24	150	130
	700	Small	3.4	109	81	210	−30
		Standard	16	129	48	160	65
		Large	40	120	27	95	105
	800	Small	4	129	95	65	−200
		Standard	20	161	60	125	−30
		Large	48	145	33	130	40
	1000	Small	5.8	186	138	−85	−320
		Standard	36	290	107	10	−175
		Large	104	313	71	40	−185
	1200	Small	8.8	283	210	−135	−320
		Standard	56	452	167	−50	−210
		Large	184	554	125	−40	−230
HEAT 3900							
8655 (0.53% C)	400	Small	2.1	67	50	175	170
		Standard	10	85	31	225	380
		Large	27	81	18	205	400
	500	Small	2.1	67	50	175	130
		Standard	9.5	77	28	175	300
		Large	32	96	22	245	300
	600	Small	2.1	67	50	250	145
		Standard	11	89	33	225	275
		Large	25	75	17	275	325
	700	Small	2.2	71	52	125	115
		Standard	10	85	31	250	215
		Large	29	87	20	185	255
	800	Small	2.3	74	55	−35	−30
		Standard	12	97	36	50	120
		Large	34	102	23	100	150
	1000	Small	4.3	138	102	−5	−250
		Standard	24	194	72	75	−105
		Large	72	217	49	160	−110
	1200	Small	7.2	232	171	−90	−320
		Standard	43	347	128	−35	−170
		Large	147	443	100	−45	−175

TABLE II.—*Concluded.*

Nominal Grade	Tempering Temperature, deg Fahr	Specimen Size	80 per cent Maximum Energy, ft-lb	80 per cent Maximum Energy per Unit Area Under the Notch, ft-lb per sq in.	80 per cent Maximum Energy per Unit Volume, ft-lb per cu in.	Transition Temperature, deg Fahr	
						80 per cent Maximum Energy Criterion	90 per cent Brittle Fracture Criterion
			HEAT 3905				
5140 (0.42% C)	400	Small	2.4	77	57	75	−40
		Standard	11	89	33	105	170
		Large	30	90	20	100	185
	500	Small	2.1	67	50	100	25
		Standard	11	89	33	115	140
		Large	30	90	20	180	210
	600	Small	2.8	90	67	210	85
		Standard	11	89	33	200	190
		Large	30	90	20	250	250
	700	Small	3.0	96	71	265	75
		Standard	16	129	48	310	170
		Large	37	112	25	285	215
	800	Small	3.8	122	90	95	−75
		Standard	18	149	55	160	20
		Large	50	151	34	165	75
	1000	Small	6.4	206	152	5	−205
		Standard	40	323	119	75	−110
		Large	128	385	87	85	−100
	1200	Small	9.8	315	233	−80	−295
		Standard	55	444	164	25	−140
		Large	192	578	131	25	−150
			HEAT 3930				
4140 (0.40% C)	400	Small	2.7	87	64	−30	−90
		Standard	14	117	43	25	20
		Large	38	114	26	−50	65
	500	Small	2.0	64	48	50	−110
		Standard	13	109	40	−30	10
		Large	38	114	26	−85	5
	600	Small	2.8	90	67	25	−20
		Standard	13	105	39	75	55
		Large	35	105	24	0	80
	700	Small	3.2	103	76	135	−50
		Standard	13	105	39	110	100
		Large	35	105	24	65	120
	800	Small	3.4	109	81	55	−95
		Standard	16	129	48	80	40
		Large	41	124	28	−45	55
	1000	Small	5.4	174	129	30	−245
		Standard	29	234	87	50	−100
		Large	91	274	62	100	−150
	1200	Small	7.5	241	179	−90	...
		Standard	49	399	148	−50	−175
		Large	168	506	114	−70	−220

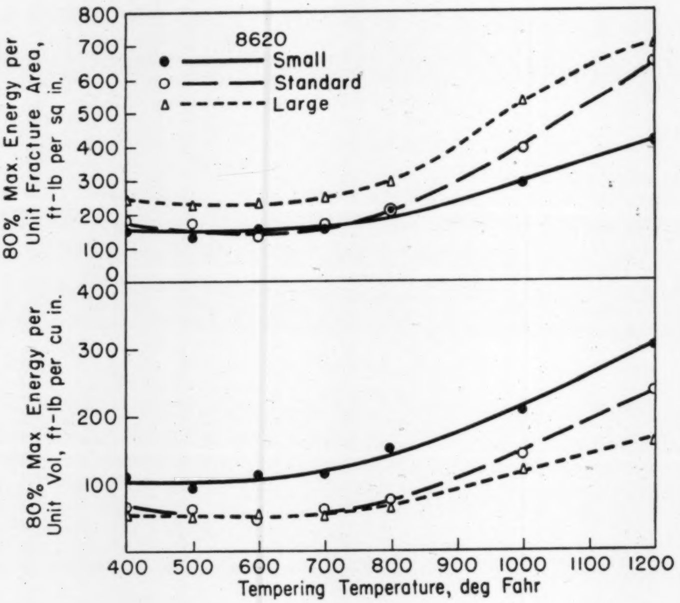


FIG. 3.—Variation of 80 per cent of Maximum Energy per Unit Fracture Area and Volume with Tempering Temperature and Size for 8620 Steel.

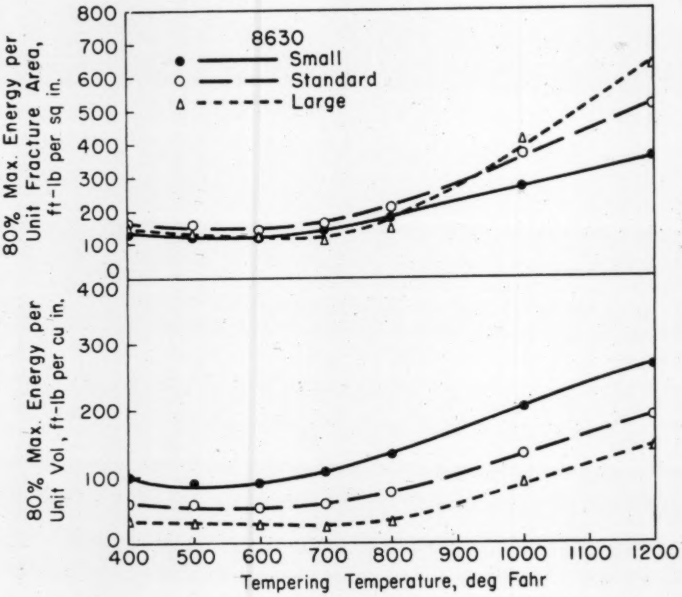


FIG. 4.—Variation of 80 per cent of Maximum Energy per Unit Fracture Area and Volume with Tempering Temperature and Size for 8630 Steel.

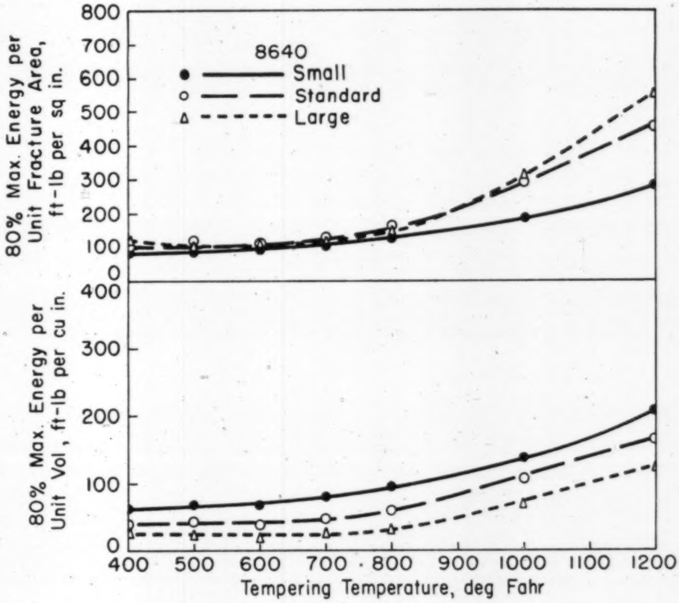


FIG. 5.—Variation of 80 per cent of Maximum Energy per Unit Fracture Area and Volume with Tempering Temperature and Size for 8640 Steel.

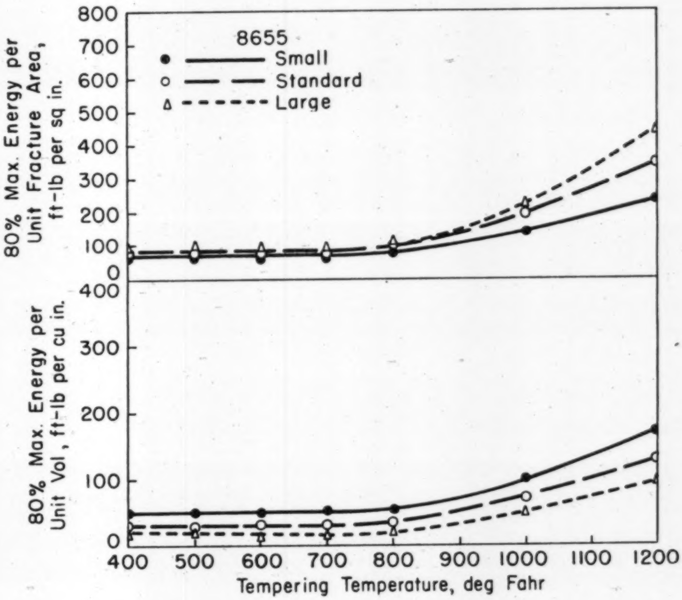


FIG. 6.—Variation of 80 per cent of Maximum Energy per Unit Fracture Area and Volume with Tempering Temperature and Size for 8655 Steel.

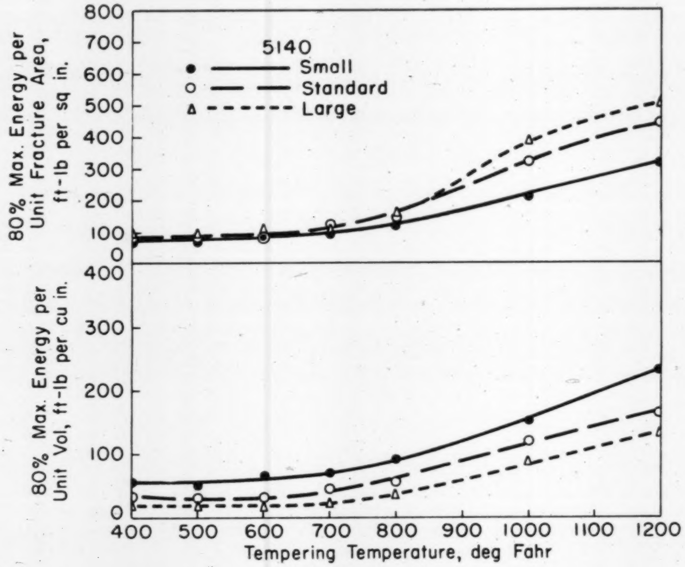


FIG. 7.—Variation of 80 per cent of Maximum Energy per Unit Fracture Area and Volume with Tempering Temperature and Size for 5140 Steel.

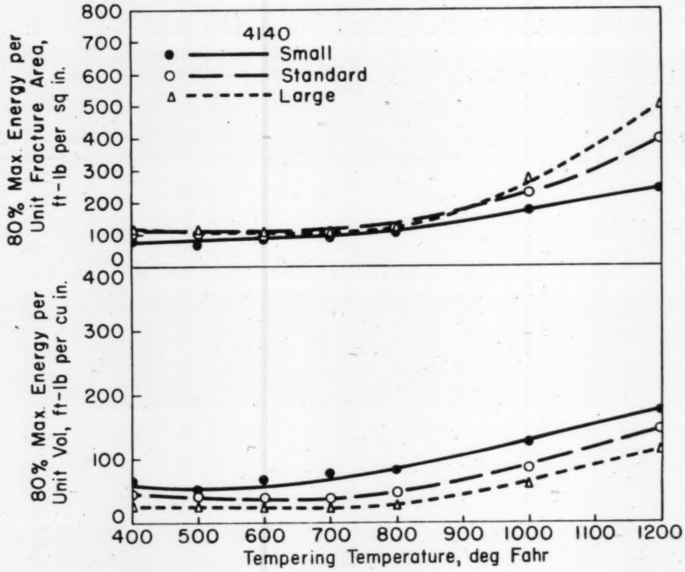


FIG. 8.—Variation of 80 per cent of Maximum Energy per Unit Fracture Area and Volume with Tempering Temperature and Size for 4140 Steel.

tabulated in Table II which also contains actual values of 80 per cent of maximum energy and values of 80 per cent of maximum energy per unit fracture area and per unit volume. The volume of the specimen was computed as the product of the three linear dimensions, the volume of the notch being disregarded.

Maximum Energy:

Consider first the effect of specimen size on maximum energy. It has been pointed out in previous investigations that the energy necessary to fracture an impact specimen consists of two parts, one part being a function of fracture area and the other a function of volume. The latter part consists of the elastic strain energy stored in the entire specimen and stressed parts of the testing machine. This stored energy is released when it reaches a value high enough to cause self-propagation of the crack without the application of further external energy. Thus, the values of 80 per cent of maximum energy obtained in this investigation have been divided by both the fracture area (area beneath the notch) and by specimen volume, and the results tabulated in Table II and plotted in Figs. 3 to 8.

Examine first the curves of impact energy per unit fracture area *versus* tempering temperature. With the exception of 8620 steel, all the steels exhibit relatively little size effect up to a tempering temperature of 700 to 800 F, that is, at the high hardness levels. At tempering temperatures from 800 F to 1200 F, or at lower hardness levels, there is a pronounced size effect, impact energy increasing with specimen size. The large specimens of 8620 steel, in contrast to the other steels, has high impact energies even at low tempering temperatures. The reason for this behavior is obscure. As has been pointed out, the large specimens of 8620 steel did not quench out completely to martensite but had 15 to 20 per cent of intermediate transformation products. The standard and small specimens did quench out completely to martensite. It seems unlikely, however, that this could explain the unusual behavior of this steel at low tempering temperatures (Fig. 3) because one might expect that, because of the presence of nonmartensitic transformation products, the curve for the large specimens should lie below those of the other two sizes.

Examine now the curves of 80 per cent of maximum energy per unit volume as functions of tempering temperature. All of these curves, once again with the exception of 8620 steel, demonstrate a size effect, maximum energy increasing with decreasing specimen size. There is very little difference between the energy absorbed by the large and standard size specimens of 8620 steel tempered from 400 to 800 F.

Transition Temperature:

Figures 9 to 14 present transition temperatures as functions of tempering temperature and specimen size using the 90 per cent brittle fracture criterion of transition temperature. Use of the 80 per cent of maximum energy criterion yields curves demonstrating the same tendencies as use of the 90 per cent brittle fracture criterion; however, there is considerable scatter in the data, the curves not being as well-defined as for the 90 per cent brittle fracture criterion.

The curves of Figs. 9 to 14 show a definite size effect, the small specimens always exhibiting lower transition temperatures than the other two sizes. There is not as much difference in transition temperature between the standard and large specimens as between

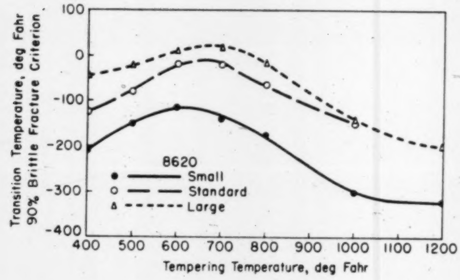


FIG. 9.—Variation of Transition Temperature with Tempering Temperature and Specimen Size for 8620 Steel.

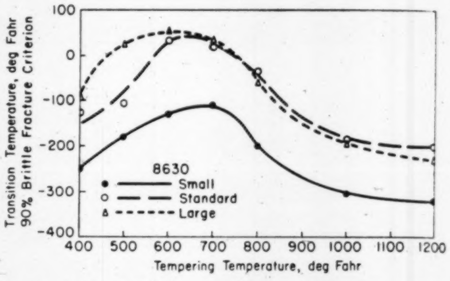


FIG. 10.—Variation of Transition Temperature with Tempering Temperature and Specimen Size for 8630 Steel.

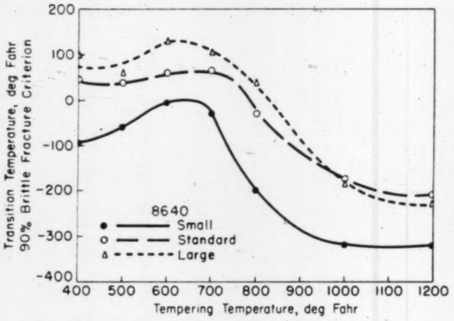


FIG. 11.—Variation of Transition Temperature with Tempering Temperature and Specimen Size for 8640 Steel.

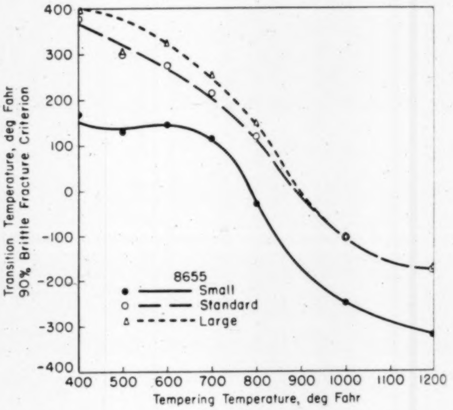


FIG. 12.—Variation of Transition Temperature with Tempering Temperature and Specimen Size for 8655 Steel.

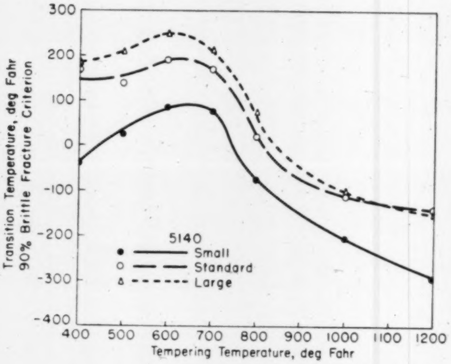


FIG. 13.—Variation of Transition Temperature with Tempering Temperature and Specimen Size for 5140 Steel.

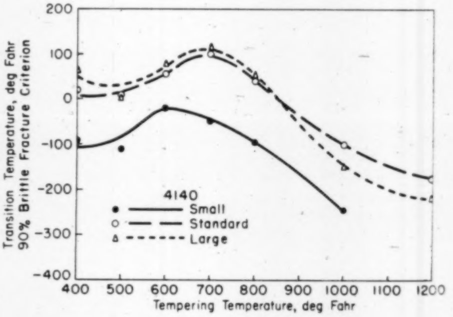


FIG. 14.—Variation of Transition Temperature with Tempering Temperature and Specimen Size for 4140 Steel.

the small and standard; in fact, the size effect between standard and large specimens is exhibited principally at high hardnesses.

It should be noted that in spite of the fact that the large specimens of 8620 steel contained 15 to 20 per cent of nonmartensitic transformation products, its behavior, Fig. 9, was no different from the behavior of the other steels.

Examination of Figs. 9 to 14 does not reveal any consistent variation of size effect with tempering temperature, carbon content, or alloy grade. If such variations do exist, they are of such a magnitude that the precision of the present experimentation was inadequate for their observation.

All the curves of Figs. 9 to 14, with the exception of 8655 steel, Fig. 12, exhibit the familiar maximum in transition temperature at a tempering temperature of 600 to 700 F, which is the so-called "500 F embrittlement phenomenon." This phenomenon has been the subject of a considerable amount of recent research; a discussion of it is outside the scope of the present paper. The transition temperature of 8655 steel at low tempering temperatures is relatively high so that the maximum is not obtained for this steel.

The 8600 series of steel at four carbon levels illustrate the effect of carbon on transition temperature, which increases with increasing carbon content. The effect of carbon content on the transition temperature of quenched-and-tempered alloy steels has been treated elsewhere (13).

CONCLUSIONS

1. Maximum impact energy per unit fracture area (area under the notch) is relatively independent of specimen size at tempering temperatures from 400 F to 700–800 F, but is dependent on specimen size at tempering temperatures between 700–800 F and 1200 F. In this region, maximum impact strength is higher the larger the specimen dimensions.

2. Maximum impact energy per unit volume decreases with increasing specimen size over the entire range of tempering temperatures investigated.

3. A distinct size effect is exhibited in transition temperature; the transition temperatures of the small specimens were considerably lower than those of the standard size specimens, which were in turn generally lower than those of the large specimens, especially at high hardnesses.

4. No consistent variation of size effect with tempering temperature, carbon content, or alloy grade is observable in the data.

5. For the 8600 series of steel, transition temperature increases with carbon content.

Acknowledgment:

The authors are grateful to the Office of Naval Research, who sponsored this work at Armour Research Foundation, for permission to publish this paper. In addition, they gratefully acknowledge their indebtedness to T. J. Kisiel and W. T. Chamberlain for carrying out the testing program.

REFERENCES

(1) G. R. Irwin, "The Effects of Size Upon Fracturing," Symposium on Effect of Temperature on the Brittle Behavior of Metals with Particular Reference to Low Temperatures, Am. Soc. Testing Mats. (To be issued as separate publication *ASTM STP No. 158*.)

(2) T. E. Stanton and R. G. C. Batson, "On the Characteristics of Notched Bar Impact Tests," *Proceedings*, Inst. Civil Engrs., Vol. 211, p. 67 (1920–1921).

(3) J. G. Docherty, "Bending Tests on Geometrically Similar Notched Bar Speci-

mens," *Engineering*, Vol. 133, p. 645 (1932). "Slow Bending Tests on Large Notched Bars," *Engineering*, Vol. 139, p. 211 (1935).

(4) P. E. Shearin, A. E. Ruark, and R. M. Trimble, "Size Effects in Steels and Other Metals From Slow Notch Bend Tests," *Fracturing of Metals*, Am. Soc. Metals, Cleveland (1948).

(5) W. F. Brown, Jr., J. P. Lubahn, and L. J. Ebert, "Effects of Section Size on the Static Notch Bar Tensile Properties of Mild Steel Plate," *Welding Journal*, Vol. 26, p. 554 Sc (1947).

(6) M. Gensamer, "Static Crack Strength of Metals," *Metal Progress*, Vol. 38, p. 59 (1940).

(7) M. L. Fried and G. Sachs, "Notched Bar Tension Tests on Annealed Carbon Steel Specimens of Various Sizes and Contours," Symposium on Deformation of Metals as Related to Forming and Service, Am. Soc. Testing Mats., p. 83 (1949). (Issued as separate publication *ASTM STP No.* 87.)

(8) N. Davidenkov, E. Shevandin, and F. Wittmann, "Influence of Size on the Brittle Strength of Steel," *Transactions*, Am. Soc. Mechanical Engrs., Vol. 69, p. A63 (1947).

(9) C. W. MacGregor and N. Grossman, "Dimensional Effects in Fracture," *Welding Journal*, Research Supplement, Jan., 1952.

(10) E. R. Parker, "The Effect of Section Size on the Fracture Strength of Mild Steel," *Fracturing of Metals*, Am. Soc. Metals, Cleveland (1948).

(11) D. C. Buffum, "Investigation of Square Sub-sized V-Notched Charpy Specimens," ASTM BULLETIN, No. 160, Sept., 1949, p. 45 (TP 143).

(12) M. Baeyertz, W. F. Craig, Jr., and J. P. Sheehan, "The Notched-Bar Impact Properties of Tempered Martensite in Medium Carbon, Medium Alloy Grades of Steel," Symposium on Effect of Temperature on the Brittle Behavior of Metals with Particular Reference to Low Temperatures, Am. Soc. Testing Mats, p. 345 (1953). (Issued as separate publication *ASTM STP No. 158.*)

(13) H. Schwartzbart and J. P. Sheehan, "The Effects of Carbon, Phosphorous, and Alloy Contents on the Notched-Bar Impact Properties of Quenched and Tempered Steels," *Report No.* 39, ONR Contract N6 onr 274 T.O.I. Project NR 031-115, Feb. 24, 1953.

DISCUSSION

MR. R. S. ZENO[1] (*presented in written form*).—The authors have done an excellent piece of work in furthering our understanding of the notched bar impact test. The only criticism I have is the omission of material hardness and strength levels for the various heat treating cycles employed.

Similar unpublished work on the effect of specimen size on notched bar impact properties was done by the writer. Forged E9310 steel of the following composition was used:

	Per cent
Carbon	0.12
Manganese	0.63
Phosphorus	0.02
Sulfur	0.028
Silicon	0.31
Nickel	3.19
Chromium	1.2
Molybdenum	0.10

Bars of this material 10 in. long by 5 in. wide by ½ in. thick were austenitized at 1500 F for 1 hr and oil quenched, then tempered at 1000 F for 1 hr and air cooled. The mechanical properties were as follows:

Tensile strength, psi	157 500
Yield strength 0.02 per cent offset, psi	137 500
Elongation in 2 in., per cent	12.5
Hardness, Rockwell C	32 to 34

The microstructure consisted of tempered martensite with some acicular ferrite.

V-notch Charpy bars of the dimensions shown in the accompanying Fig. 15 were machined from the heat-treated bars.

Energy transition temperatures were determined by estimating the temperature of greatest slope of the curves of impact energy *versus* temperature and were as follows:

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[1] Materials and Processes Laboratory, Large Steam Turbine-Generator Dept., General Electric Co., Schenectady, N. Y.

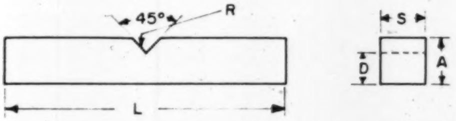
Bar Size	Energy Transition Temperature, deg Cent
$\frac{1}{4}$ size	−70
$\frac{1}{2}$ size	−35
Standard	0

It is interesting to report that we also found a distinct size effect, as the transition temperatures of the smaller specimens were considerably lower than that of the standard size bar. This relationship was very nearly linear. We found, however, that the maximum impact energy was lowered as the unit fracture area increased (Table III). This finding disagrees with conclusion 1 of the paper. In partial explanation of this difference, it appears that the maximum energy absorbed is not only a function of the unit fracture area (area under the notch), but of the specimen geometry as well.

In addition, we also found that the maximum energy per unit volume decreases with increasing specimen size (Table III).

In general, the findings of our investigation were in good agreement with the conclusions presented in this paper.

MESSRS. J. A. KIES[2] **AND G. R. IRWIN**[2] (*presented in written form*).—It is appreciated that the authors pointed out in early portions of their paper that the energy and velocity of the striker could not be scaled and that the root radius of the notch was held constant as an expedient not inconsistent with other deviations of the test procedure from what one might want for a scholarly study of fracture size effects. Within the necessary complexities presented by these impact tests from an interpretive viewpoint, it is believed unwise to use maximum impact energy per unit fracture area as meaning "impact strength" as is done in the authors' first conclusion. If there exists a significant test volume size which can be employed in an energy per unit volume ratio to obtain a quantity deserving the name impact strength, that significant test volume might, so far as one knows, be proportional to any power of the test size from one to three. In these impact tests there is not likely to be any special relation of the observed energy loss to the severed area itself, since most of the energy is required just to obtain a well-started initial crack rather than to propagate the crack across the specimen.



Bar Size	L, in.	S, in.	D, in.	A, in.	R, in.	Volume, cu in.	$S \times D$ Fracture Area, sq in.	Capacity of Impact Machine, ft-lb	Hammer Striking Velocity, ft per sec
Standard	2.165	0.394	0.315	0.394	0.010	0.335	0.124	120	11.3
$\frac{1}{2}$ size	2.165	0.197	0.315	0.394	0.010	0.168	0.062	120	11.3
$\frac{1}{4}$ size	2.165	0.098	0.315	0.394	0.010	0.084	0.031	16	11.2

FIG. 15.—Specimen Dimensions.

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[2] Physicist and Superintendent, respectively, Mechanics Division, Naval Research Laboratory, Washington, D. C.

The authors stated that self-propagation of their cracks occurred when the stored energy reached a high enough value. The potential strain-energy release rate and the total strain energy usually increase together as the load on the specimen increases and the starting crack forms. However, it is the strain-energy release rate the magnitude of which is critical with respect to self-propagation. The strain-energy release rate depends upon the crack depth as well as upon the load.[3, 4] The magnitude of the total strain energy should be regarded more as an energy reservoir for continuing an already started self-propagating crack rather than as the reason for onset of unstable fast fracturing.

TABLE III.—ENERGY PER UNIT VOLUME AND UNIT FRACTURE AREA AS A FUNCTION OF SPECIMEN SIZE.

Temperature, deg Cent	Total Energy,[a] ft-lb			Energy per Unit Volume, ft-lb			Energy per Unit Fracture Area, ft-lb		
	¼ Size	½ Size	Full Size	¼ Size	½ Size	Full Size	¼ Size	½ Size	Full Size
−195	2.7	3.8	6.1	32.2	22.6	18.2	87.2	61.3	49.2
−110	3.0	5.8	17.0	35.7	34.5	50.8	96.8	93.6	137.1
−75	6.3	8.5	23.0	75.0	50.6	68.7	203.2	137.1	185.4
−25	9.6	12.6	23.3	114.2	75.0	70.2	309.8	203.2	187.8
+22	9.5	18.5	32.5	113.1	110.1	97.1	306.1	298.8	261.0
+50	9.0	19.0	32.5	107.1	113.1	97.1	290.0	306.5	261.0

[a] Average of 3 values.

Regarding the variations in nonmartensitic transformation products mentioned by the authors, it seems worth noting that a considerable amount of work has been published on the effects of such constituents on notched-bar impact properties. Hodge and Lankford[5] found that in SAE 4340 steel at a given hardness level the impact properties were not significantly affected by 1 to 5 per cent of upper bainite or by 5 per cent ferrite. The impact properties at a given hardness level were significantly lowered by 10 per cent or more of upper bainite and also by 5 per cent or more of pearlite. Bailey[6] showed for those steels, including AISI 5140, that 10 per cent nonmartensitic transformation products have very little effect on impact energy *versus* temperature curves although 30 per cent is detrimental. On the basis of the above published results, it can be assumed that the impact energies for only the large-sized specimens of 8620 steel were probably influenced by microstructure, although the trend in size effect does not seem to have been unduly upset thereby.

MESSRS. HARRY SCHWARTZBART AND J. P. SHEEHAN (*authors' closure*).—The authors appreciate the comments of Mr. Zeno and Messrs. Kies and Irwin.

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[3] G. R. Irwin and J. A. Kies, "Fracturing and Fracture Dynamics," *The Welding Journal*, Research Supplement, Feb., 1952, p. 95s–100s.

[4] G. R. Irwin and J. A. Kies, "Critical Energy Rate Analysis of Fracture Strength," *The Welding Journal*, Research Supplement, April, 1954, p. 193s–198s.

[5] J. M. Hodge and W. T. Lankford, "Influence of Nonmartensitic Transformation Products on Mechanical Properties of Tempered Martensite," Technical Note *No. 2862*, Nat. Advisory Comm. Areonautics, Dec., 1952.

[6] E. F. Bailey, "Effect of Nonmartensite Decomposition Products on the Properties of Quenched-and-Tempered Steels," *Transactions*, Am. Soc. Metals, Vol. 46, p. 830 (1954).

To correct an unwarranted omission of data from the paper, hardness data are herein presented for the various steels investigated. Tensile strengths were not determined.

Steel	Hardness, R_c, of Standard Size Specimens						
	400[a]	500	600	700	800	1000	1200
8620......	43	43	42	41	39	31	23
8630......	49	48	46.5	44	42	35	28
8640......	53.5	51	48.5	47	45	38	30
8655......	57.5	56	52	50	47	41	33
5140......	54	51	49	47.5	44.5	35	27
4140......	54	52	50	48.5	45	39	30

NOTE.—Hardness of subsize and oversize specimens was the same as those shown for standard specimens, with exception of oversize specimens from the 8620 grade which were 2–3 R_c lower.

[a] Tempered for 1 hr at indicated temperatures.

With respect to the comments of Messrs. Kies and Irwin, the authors would like to indulge in a bit of speculative rambling (which, possibly, is allowable in a discussion if not in a paper).

Attempting to rationalize size effect results over the range of strength levels investigated in the present paper is indeed difficult. The authors wonder if the comments of Kies and Irwin in respect to energy per fracture area do not apply more to "strong" specimens (low tempering temperature) than to "weak" specimens (high tempering temperature). Certainly the relative amounts of energy needed to start the crack and to propagate the crack vary with tempering temperature, and this may account for conclusion 1, namely, that one set of size effect results (energy per fracture area) are obtained at tempering temperatures between 400 and 700 F and another set at tempering temperatures between 800 and 1200 F. In other words, at low tempering temperatures the material is relatively strong and brittle (by brittle, meaning low inherent ductility). Most of the impact energy is required to start the crack. When the crack reaches a given length, the release of stored strain energy promotes self-propagation without additional assistance from the hammer needed. Under these conditions, certain size effects are obtained. At high tempering temperatures the material is relatively weak and ductile (relative to low tempering temperatures). Some impact energy is required to initiate the crack. At this point some strain energy has been stored, but not as much as at the initiation of the crack for strong, brittle specimens. The hammer continues to supply energy to propagate the crack for a longer time than for strong, brittle specimens and may even have to supply energy to propagate the crack the whole way through the specimen. Thus, a different size effect is obtained. The authors believe that all of this may account for the observations leading to conclusion 1.

NOTCH-BAR TESTS OF HIGH-STRENGTH STEEL*

By R. Raring[1] and J. Rinebolt[1]

Synopsis

Charpy V-notch specimens of AISI 4340 steel heat treated to 210,000 psi and 230,000 psi were tested at temperatures ranging from 320 F to −320 F by the conventional impact test and by slow bending. Energy absorption in the slow-bend test was calculated from automatically recorded load-deflection curves. The volume of plastically strained metal in the broken specimens was also used as a measure of ductility.

Energy absorption indicated by the impact test was much higher than energy absorption calculated from load-deflection data of the slow test. The volume of plastically strained metal in the specimens tested by impact, however, was not significantly different from that of specimens tested slowly. The mechanism of crack formation and extension in V-notch Charpy specimens of high-strength steels is shown to be different from that of pearlitic steels or softer quenched and tempered steels.

During the past few years there has developed a strong and growing demand for constructional steels with much higher strength than has been traditional for such steels. A tensile strength of about 180,000 psi used to be accepted as the maximum above which the notch ductility of steel was considered inadequate for important structural members. This maximum is no longer universally accepted. Steels with strengths as high as 250,000 psi have been used in such critical parts as aircraft landing gear, and the possibilities of using even higher strength levels are under serious consideration.

Of the several serious impediments to the use of high-strength steels (that is, steels with tensile strength greater than 200,000 psi), their relatively low ductility is the most important. In the course of development and appraisal of such steels, it is necessary to select tests and parameters for notch ductility evaluation. The Charpy notch-bar test is often used for this purpose. This paper serves to call attention to difficulties in the usual interpretation of results of V-notch Charpy tests of high-strength steels, which either do not arise or are less serious in tests of softer martensitic or pearlitic steels, and to suggest an alternative interpretation.

In V-notch Charpy tests of softer steels, there is a change in the fracture appearance from a silky, fibrous fracture above the transition temperature to a bright, granular fracture below this

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13–18, 1954.

[1] Head and Metallurgist, respectively, Ferrous Alloys Branch, Metallurgy Division, Naval Research Laboratory, Washington, D. C.

transition; simultaneously, there is a fairly abrupt decrease in the energy absorption.

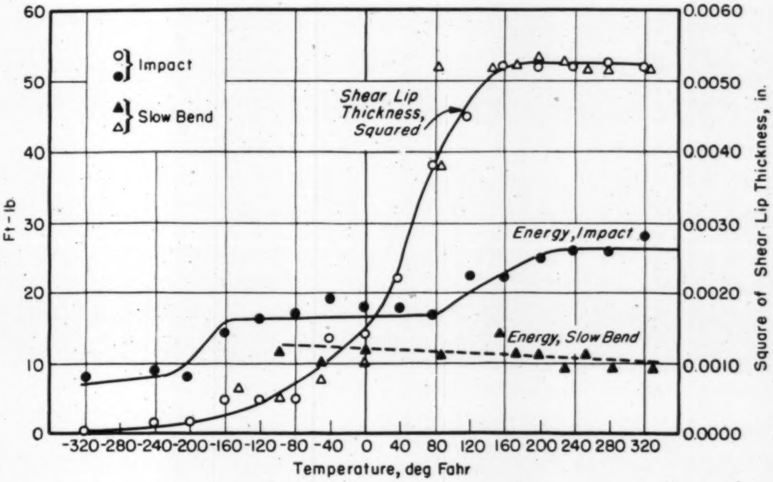

Fig. 1.—Variation of Energy and Shear Lip with Temperature in Impact and Slow Tests of Charpy V-Notch Specimens of AISI 4340 Steel, Tensile Strength 230,000 psi.

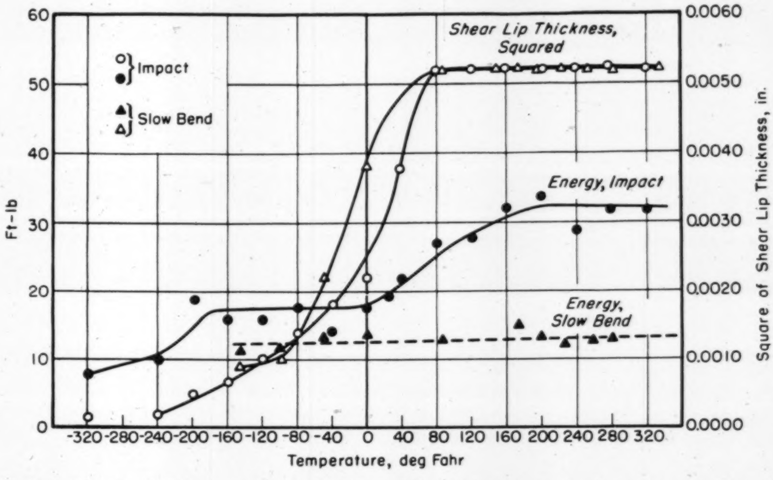

Fig. 2.—Variation of Energy and Shear Lip with Temperature in Impact and Slow Tests of Charpy V-Notch Specimens of AISI 4340 Steel, Tensile Strength 210,000 psi.

For high-strength steels there is no marked change in the fracture appearance as the test temperature is changed, except for a thickening of the shear lip along the edge of the bar. The energy absorption varies very gradually with temperature, not abruptly as with softer steels. Often, within the transition range, there is no significant change in energy absorption when the temperature is varied by 200 F or more. The criteria for ductility and the definitions of transition temperature used for softer steels are therefore less satisfactory for high-strength steels.

IMPACT TESTS OF HIGH-STRENGTH STEEL

Some results of Charpy V-notch tests of AISI 4340 steel, oil quenched from 1550 F and tempered at 700 F (tensile strength 230,000 psi) and 800 F (tensile strength 210,000 psi) are shown in Figs. 1 and 2 to illustrate certain of the points made above. The results are typical of those obtained with other heats of AISI 4340 and at other high-strength levels. The energy-temperature curve, for the impact tests, shows a very gradual decrease in energy absorption as temperature decreases. The portion of the curve from +80 to −160 F (Fig. 1) is drawn with zero slope and seems to fit the data about as well as any other smooth line would. It is evident that the determination of a transition temperature on such curves is difficult, especially when the energy level used to define the transition temperature is near the level of the energy plateau on the curve.

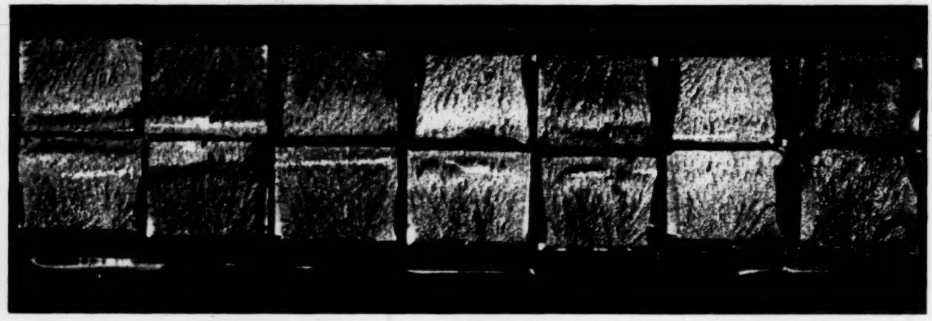

FIG. 3.—Fracture Faces of Charpy Specimens of AISI 4340, Tensile Strength 230,000 psi, Tested Between 80 and −160 F. All indicated about the same energy absorption in impact test.

The specimens represented by the points on the energy plateau (+80 to −160 F) of the impact curve of Fig. 1 are shown in Fig. 3. It can be seen that most of the area of the fracture face is granular, typically characteristic of fast, brittle fracture. It is apparent that the thickness of the shear lip along the sides of the specimen narrowed as the test temperature decreased. This change in the thickness of the shear lip of specimens tested from +80 to −160 F seems to contradict the uniformity of the energy absorption observed over the same temperature range. Alternately, it may be deduced that the energy absorption due to the shear lip is relatively small.

SLOW-BEND TESTS OF HIGH-STRENGTH STEELS

The behavior of these steels was investigated further using V-notch Charpy specimens tested slowly. The test method and apparatus has been described in detail.[2] Briefly, the bar is supported and loaded exactly as it is in the impact test with the exception that the load is applied slowly in a universal testing machine. The load-deflection curve is automatically recorded and the energy to fracture is calculated from planimeter readings of the area under the curve.

The energy-temperature relationships determined by slow-bend tests are also shown in Figs. 1 and 2. It is evident that they are very unlike the impact curves.

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[2] R. Raring, "Load-Deflection Relationships in Slow-Bend Tests of Charpy V-Notch Specimens," *Proceedings*, Am. Soc. Testing Mats., Vol. 52, p. 1034 (1952).

In slow bending, the energy did not decrease when the test temperature was lowered from +320 down to −100 F; in fact the curve indicates a tendency for the energy to rise as temperature is decreased. This effect will be explained later.

The dissimilarity between the curves for the fast test and slow tests was surprising for at least two reasons. First, it has previously been shown by several investigators in tests of softer steels, for example, in reference (1), that slow tests of the various notch-impact specimens will give the usual kind of energy-temperature curve; the slow tests almost always indicate a lower energy absorption above the transition temperature and, usually, a lower transition temperature. But the very marked differences in the two curves, as shown in Figs. 1 and 2, were never found in these previous tests of softer steels. The second rather surprising and seemingly contradictory finding was that specimens broken by the two test methods at any given temperature were undistinguishable in appearance. This was surprising because it normally would be expected that the degree of plastic strain would increase as energy absorption increases, but even though the energy in the impact test was as much as three times as great as in the slow test (for example, the 320 F tests of Fig. 1), the broken specimens were indistinguishable.

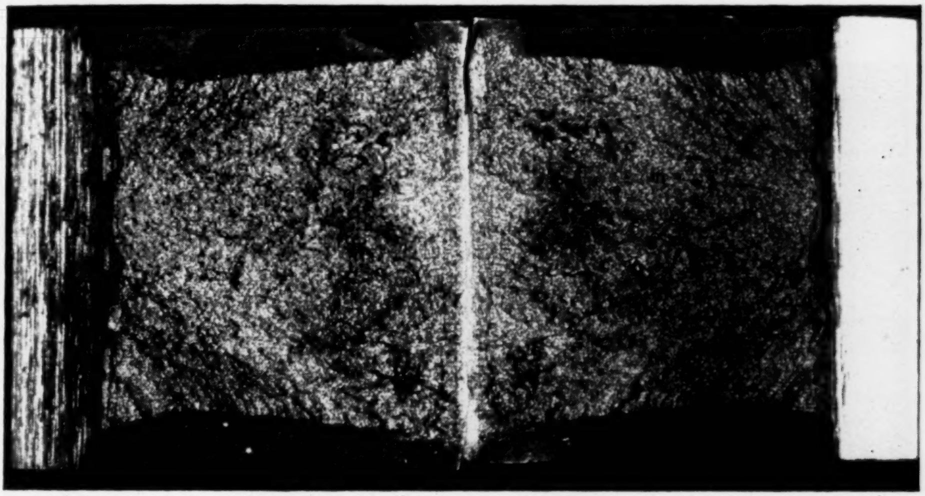

FIG. 4.—Typical Shear Lip of Fractured Charpy Specimen of High-Strength Steel.

SHEAR LIP ON BROKEN SPECIMENS

In both the impact tests and the slow-bend tests, it was observed that the thickness of the shear lip along the sides of the fracture decreased as the test temperature decreased. This temperature effect is shown on Figs. 1 and 2 by the plot of the square of the depth of the shear lip *versus* the testing temperature for both fast and slow tests. The curves representing the fast and slow tests show near superimposition.

The reason for plotting the square of the depth rather than depth itself is not entirely an arbitrary one, for it is reasonable to conclude that the square more closely represents the volume of the strained metal, and therefore more closely represents ductility and energy, than does the depth itself. Figures 4 and 5 illustrate the characteristic appearance and shape of the shear lip and the strained area on the side of the specimen behind the fracture. It was observed that the maximum depth (Fig. 4) was always about half of the width of the strained area on the side of the specimen (Fig. 5) at its widest point. From these observations, it is considered that the volume of strained metal associated with the shear lip assumes the shape, approximately, of one half of a prolate spheroid with a major axis equal to the thickness of the specimen at the root of the notch. The volume, therefore, would vary approximately as the square of half the minor axis, that is, the square of the depth of the shear lip.

It is suggested that the variation of the square of the depth of the shear lip with temperature is a more sensitive index of the effect of temperature on ductility than are the energy values taken from the impact machine or calculated from the data of the slow-bend test. Furthermore, the shear lip curve more closely resembles the temperature-ductility relationships observed in tests of softer steels when the conventional parameters for ductility are used and permits a more precise determination of a transition temperature, by any of the definitions of transition temperature, than the energy curves.

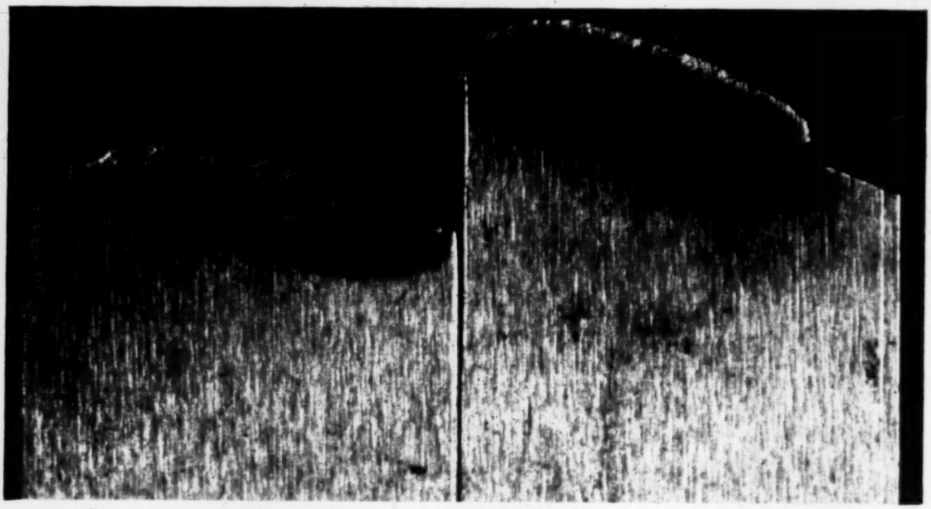

FIG. 5.—Typical Elliptic Shape of Plastically Strained Area on Side of Fractured Charpy Specimen of High-Strength Steel.

DISCUSSION

In order to explain why the energy-temperature curves for the slow-bend tests do not indicate a transition (see Figs. 1 and 2), it is necessary to consider the load-deflection curves for tests at the various temperatures. When softer steels (less than 180,000 psi tensile strength) are tested at temperatures above the transition temperature, curves similar to *C* in Fig. 6 are obtained. There is first a straight, elastic portion, followed by yielding and bending of the specimen. Plastic strains develop throughout a large volume extending to as much as $\frac{1}{2}$ in. on either side of the notch. Soon after yielding has occurred, a small shear crack develops which slowly widens and deepens as the test progresses, until finally the specimen is separated by a tearing-like action. External energy from the testing machine must constantly be supplied to advance the crack. As the test temperature is lowered to below the temperature at which brittleness begins, the shear crack becomes unstable late in the course of the test and extends for a very small distance as a fast cleavage crack. In the fractured specimen, this fast part of the crack is manifested by the familiar small patch of graininess, which contrasts with the fibrous part developed by the slow advancement. When the small fast crack occurs, the load drops abruptly, thus decreasing the area under the load-deflection curve. In this same fashion, further lowering of the test temperature causes a gradual enlargement of the fast granular crack accompanied by a gradual attrition of the work area under the curve, and results in the usual energy-temperature relationship. Examples of load-deflection curves and transition curves for pearlitic steels and softer martensitic steels are shown in the earlier report.[2]

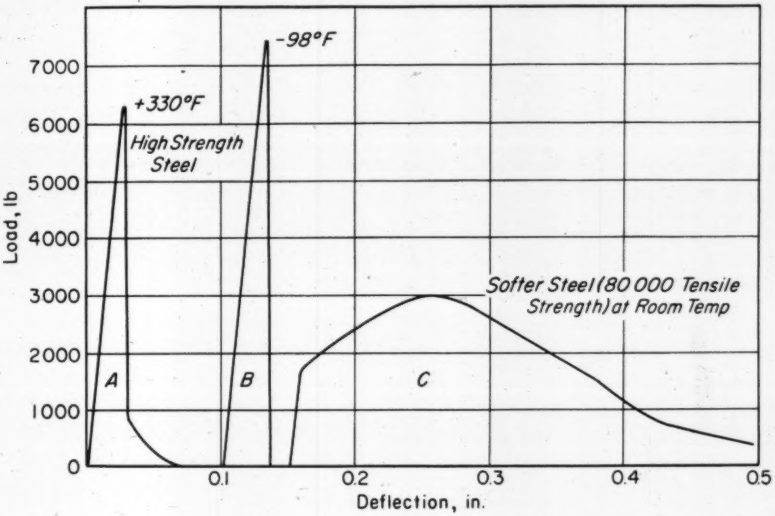

FIG. 6.—Typical Load-Deflection Curves from Slow-Bend Tests of Charpy V-Notch Specimens of AISI 4340 at 230,000 psi Tensile Strength (*A* and *B*) and Pearlitic Carbon Steel of 0.30 per cent Carbon (*C*).

High-strength steels tested in slow bending show entirely different results. In tests at temperatures as high as 330 F, no slowly advancing shear cracks were observed, no plastic bending occurred on the specimen, and in no instance did a load-deflection curve like *C* of Fig. 6 develop. Instead, the load deflection curves at all test temperatures were like curves *A* and *B* of Fig. 6. Curve *A* indicates that even at 330 F the deflection was elastic up to the fracture point. The crack started at this point, and the elastic energy was sufficient to drive a fast, instantaneous crack almost completely through the specimen without the addition of more energy from the machine. The small tail on the end of the curve is a measure of the small amount of additional work that had to be supplied by the machine to complete the fracture. This area is included in the energy calculation. As the test temperature was lowered, this same behavior occurred until at about 80 F the elastic energy was sufficient to complete the fracture, and the curve had no tail. As the temperature was lowered further, the elastic strain energy available at the maximum load remained constant or increased slightly, while the energy absorbed by the fracturing process progressively decreased. Thus the steel undergoes a transition which the energy-temperature curve does not show. The difference between these two energy values appeared as kinetic energy of the broken specimen, which was thrown from the machine with increasing speed as the test temperature was lowered.

The load-deflection curve for a −98 F test is shown as *B* in Fig. 6. Notice that maximum load is greater than that of the higher temperature test. There was small but constant trend toward higher loads as the temperature was lowered. The higher elastic strain energy associated with the higher load was sufficient, or slightly more than sufficient, to compensate for the energy associated with the tail of the curve. Tests below 80 F did not have a tail as in curve *A* of Fig. 6. This is reflected by the lack of slope, or the slightly negative slope, of the energy-temperature curves for the slow-bend tests shown by Figs. 1 and 2.

It is evident that the impact test indicates a much higher energy absorption at high temperatures than does the slow-bend test. The greater energy absorption in the fast test suggests that a high strain rate has the effect of increasing the strength or ductility or both. But the fact that there is no obvious difference in the physical evidences of plastic strain on the specimens broken at the same temperature by fast and slow tests indicates that there was no effect of strain rate on the amount of plastic strain. It has often been shown that increasing the strain rate can raise the yield load,[3] but such an effect does not provide a satisfactory or likely explanation of the energy difference, because the broken specimens show no evidence of bending. Clarification of this strain-rate effect would be possible by making dynamic load-deflection diagrams during impact testing. This approach would require elaborate instrumentation, however, and was beyond the scope of this investigation.

In comparing the impact curves at the two strength levels, it can be observed that the maximum energy is lower for the steel of higher strength, and that the first decrease in energy absorption occurs at a higher temperature for the higher strength steel. The shear lip measurement also indicates a higher transition for the higher strength steel. The energy data from the slow-bend test, on the other hand, do not indicate a transition, for reasons explained above.

FINDINGS

1. The thickness of the shear lip on broken V-notch Charpy specimens of high-strength steels provides a potentially useful index of ductility.

2. Energy absorption indicated by the impact test exceeds the energy absorption calculated from results of slow-bend tests.

3. There is little or no difference in the volume of plastically strained material on specimens broken by impact and those broken in slow bending.

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[3] W. Schwinning and K. Matthaes, "The Significance of the Notch Impact Test," Deutscher Verband für Materalprufüng der Technik Report No. 78 (1927).

DISCUSSION

Mr. J. A. Kies[1].—When a Charpy specimen is broken it seems reasonable to suggest that the maximum fiber stress must reach a typical value characteristic of the material and dimensions of the test piece. Although fast fracture begins when the rate of release of elastic energy equals or exceeds the rate of absorption in crack propagation this condition is not dictated by the total elastic energy content of the specimen. If this happens to be in excess of the total amount required for completion of the fracture, the excess will be dissipated in various ways but will all be included in the measurement of energy absorbed. In the case of high-strength materials with moderate or low values of energy absorption per unit fracture area, high bending loads are required which are likely to require the input of so much elastic energy in the specimen that the Charpy impact test may not be a satisfactory measure of the energy for fracture.

Mr. R. H. Raring (*author*).—Mr. Kies has offered a rationalization of the failure of high-strength steel to indicate an energy transition with temperature in slow tests of Charpy V-notch specimens. The authors agree with his explanation. It points out an essential difference between high-strength steel and softer steels in this test which should be taken into consideration by investigators who use this type of test in the evaluation of high-strength steel.

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[1] Physicist, Mechanics Division, Naval Research Laboratory, Washington, D. C.

THE STRENGTH OF CARBON STEELS FOR ELEVATED-TEMPERATURE APPLICATIONS*

By R. F. Miller[1]

At the request of the ASME Boiler Code Subcommittee on Stress Allowances for Ferrous Materials, the ASTM-ASME Joint Committee on Effect of Temperature on Properties of Metals has conducted an investigation of the strength of carbon steels for elevated-temperature applications. The project was assigned to the Petroleum and Chemical Panel of the Joint Committee, and the tests were carried out cooperatively by the following companies:

Babcock & Wilcox Co.
Bethlehem Steel Co.
General Electric Co.
Inland Steel Co.
Jones & Laughlin Steel Corp.
National Tube Division, U. S. Steel Corp.
Timken Roller Bearing Co.
Youngstown Sheet and Tube Co.
United States Steel Corp.

The purpose of this investigation was to provide reliable information on the elevated-temperature strength of present-day carbon steel plate and seamless pipe, in the condition in which it is used in service, for the assistance of the Boiler Code Subcommittee in evaluating the allowable working stresses for such materials. The steels selected conformed to the following ASTM Specifications: Grade B of Tentative Specifications for Carbon-Silicon Steel Plates of Intermediate Tensile Ranges for Fusion Welded Boilers and Other Pressure Vessels (A 201 - 52*a* T)[2], and Grade B of Tentative Specification for Seamless Carbon-Steel Pipe for High-Temperature Service (A 106 - 52 T).[2] In order to study the effect of manufacturing practice, heats with high and low grain-coarsening temperatures (made with and without aluminum as a final deoxidizer) were included in the investigation. Elevated-temperature tension, creep, and rupture tests were carried out, and the grain-coarsening characteristics were determined. The original plans for this investigation called for testing the plate material in the stress-relieved condition and the seamless pipe material in the as-rolled condition in order to simulate as closely as possible the condition in which these materials are used in elevated-temperature applications.

CARBON PLATE STEEL

The chemical composition of the carbon plate steel heats is shown in Table I, together with the actual ferrite grain size, McQuaid-Ehn grain size, and austenite grain-coarsening characteristics. Six heats of the plate steel (ASTM A 201, Grade B) were tested, three having been made to coarse-grain practice and three to fine-grain practice.

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13-18, 1954.

[1] United States Steel Corp., Pittsburgh, Pa.

[2] 1952 Book of ASTM Standards, Part 1, p. 410 and p. 40.

TABLE I.—CHEMICAL COMPOSITION, GRAIN SIZE, AND FINAL DEOXIDATION PRACTICE OF PLATE STEEL HEATS.

Type of Manufacturing Practice	Heat Designation	Chemical Composition, per cent											Ferrite Grain Size[b], ASTM Number	McQuaid-Ehn Grain Size[e], ASTM Number	Austenite Grain-Coarsening[f] Temperature, deg Fahr	Ladle Deoxidation
		Carbon	Manganese	Phosphorus	Sulfur	Silicon	Total Aluminum[a]	Aluminum Oxide[a]	Total Nitrogen[b]		Nitrogen as Aluminum Nitride[b]					
									AR[c]	SR[d]	AR[c]	SR[d]				
Coarse Grain.......	B	0.16	0.55	0.013	0.032	0.24	0.005	0.003	...	0.004	...	0.0003	6	1–3	1600–1700	Si-Mn, Fe-Si, Fe-Ti, No Al
Coarse Grain.......	CG1	0.19	0.57	0.023	0.034	0.19	0.006	0.002	0.005	0.004	0.0002	0.0003	5–6	2–4	1600–1700	Fe-Mn, Fe-Si, C-Si, No Al
Coarse Grain.......	CG2	0.20	0.66	0.028	0.034	0.27	0.015	0.003	0.005	0.004	0.0002	0.0006	6	3–4	...	Fe-Mn, Fe-Si, C-Si, No Al
Fine Grain.........	I	0.20	0.70	0.015	0.029	0.18	0.044	0.003	0.004	0.006	0.0004	0.0014	6–7	6–8	1700–1800	Fe-Mn, Fe-Si, Fe-C-Ti, 1.4 lb Al per ton
Fine Grain.........	FG1	0.19	0.68	0.026	0.036	0.24	0.053	0.004	0.004	0.004	0.0008	0.0022	5–6	6–7	1700–1800	Fe-Mn, Fe-Si, 2.4 lb Al per ton
Fine Grain.........	FG2	0.18	0.66	0.031	0.032	0.26	0.051	0.003	0.004	0.004	0.0009	0.0023	6–7	6–7	...	Fe-Mn, Fe-Si, 2.3 lb Al per ton

[a] Aluminum and aluminum oxide determination by Jones & Laughlin Steel Corp.

[b] Nitrogen and ferrite grain size by U. S. Steel Corp.

[c] AR—As rolled.

[d] SR—stress relieved.

[e] McQuaid-Ehn Grain Size by Timken Roller Bearing Co.

[f] Austenite Grain-Coarsening Temperature by Youngstown Sheet and Tube Co.

Chemical composition of A 201, Grade B: 0.24 max carbon, 0.80 max manganese, 0.035 max phosphorus, 0.04 max sulfur, 0.15 to 0.30 silicon.

The final ladle additions are also shown in Table I. In line with the original plans for this investigation, the plate steel heats were rolled to 1-in. thick plates and tested after stress relieving for 2 hr at 1150 F. Additional tension tests were carried out on these materials in the as-rolled condition in order to obtain more information on their strain-aging characteristics.

Austenite Grain-Coarsening Characteristics:

The austenite grain-coarsening characteristics of these steels were determined by the Youngstown Sheet and Tube Co. The gradient-quench method (1)[3] was employed, consisting of heating a small specimen ($1\frac{1}{2}$ by $\frac{1}{2}$ by $\frac{1}{8}$ in.) to the desired temperature for 60 min and quenching one end in brine. Precaution was necessary to avoid the formation of excessive scale while heating the specimen. The grain size was determined in the zone adjacent to the quenched end, where the austenite grains were outlined by fine pearlite. The results of the tests on plate steels are shown in Table II. Since steels CG2 and FG2 were duplicates of CG1 and FG1, it was felt that it would be unnecessary to carry out grain-coarsening studies on these materials.

TABLE II.—AUSTENITE GRAIN-COARSENING CHARACTERISTICS OF PLATE STEEL HEATS.

Type of Manufacturing Practice	Heat Designation	Austenite Grain Size[a] After 60 min at Temperature				
		1600 F	1700 F	1800 F	1900 F	2000 F
Coarse Grain	B	6	2–4	3–4	3	3
Coarse Grain	CG1	3–6	4	4	3–4	2–3
Fine Grain	I	6–7	6	1–6	2–3	4–5
Fine Grain	FG1	6–7	6–7	1–6	2–3	3–4

[a] ASTM grain size number.

Table II shows that the heats made to coarse-grain practice (no aluminum) begin to coarsen between 1600 and 1700 F. The heats made to fine-grain practice, both of which received a final deoxidation with aluminum, remained fine-grained up to 1700 F, and began to coarsen between 1700 and 1800 F. Both of the aluminum deoxidized heats showed a duplex grain size at 1800 F, and continued to coarsen up to 1900 F, after which there was a slight reduction in the grain size.

Despite the differences in austenite grain-coarsening characteristics, the actual ferrite grain size of all six heats was about the same, ranging from No. 5–6 to No. 6–7. The size and appearance of the pearlite areas were also about the same in all six heats as is shown in Fig. 1. It thus appears that the hot working of the slab to the plate has more influence on the actual ferrite grain size and microstructure than does the austenite grain-coarsening temperature.

Tensile Strength:

The tensile strength of the six plate steel heats at room temperature, 200, 400, 600, 800, and 1000 F are shown in Table III and the results are plotted in Figs. 2, 3, 4, and 5. It will be seen from Fig. 2 that all three of the plate heats made to coarse-grain practice show a considerable rise in tensile strength in the neighborhood of 400 to 600 F. By this criterion, these materials are thus seen to be susceptible to strain aging in

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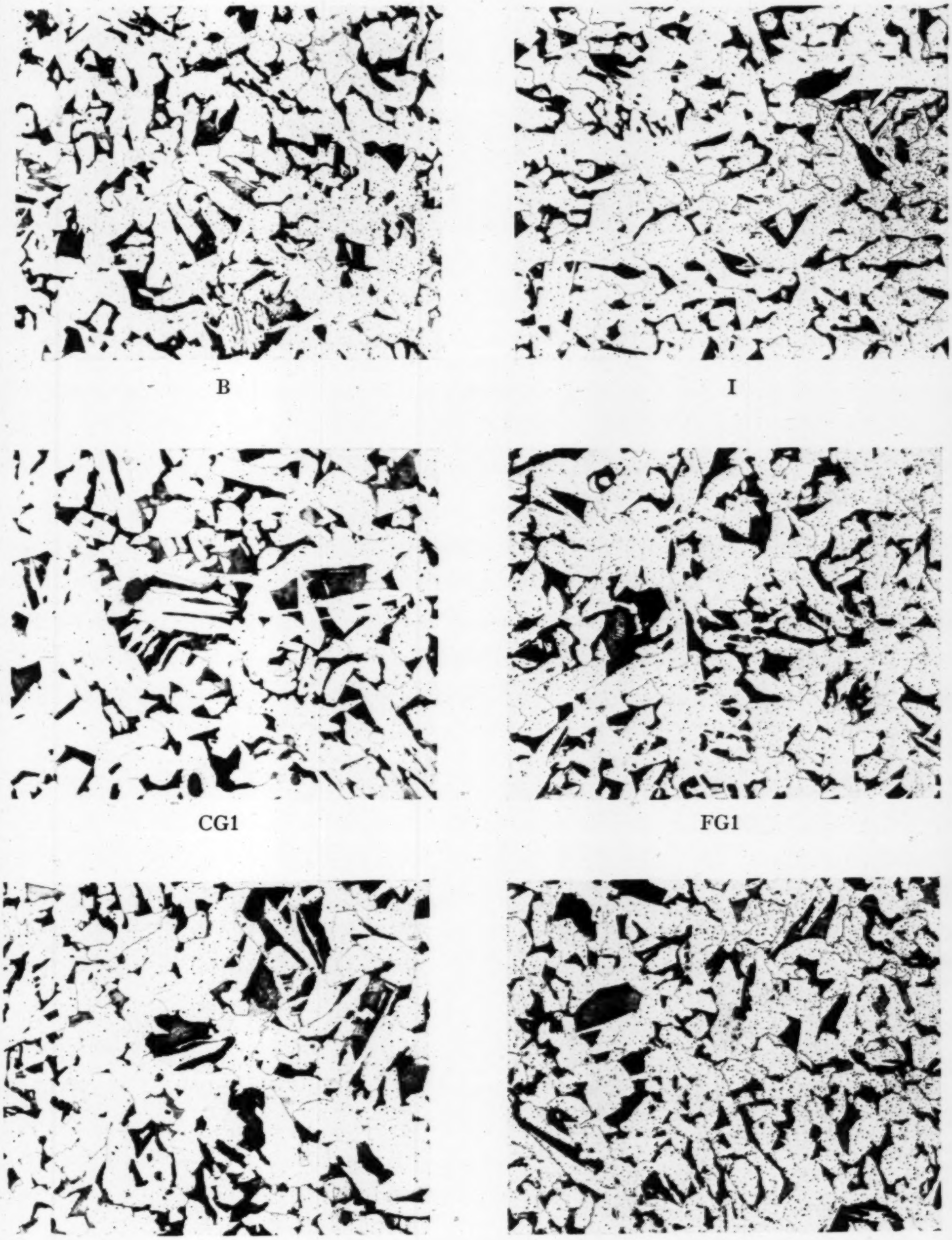
[3] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 986.



Coarse-Grain Practice

Fine-Grain Practice

B

I

CG1

FG1

CG2

FG2

FIG. 1.—Microstructure of Plate Steel Heats—Nital Etch (× 100).

TABLE III.—TENSION TEST RESULTS FOR PLATE STEEL HEATS.

Type of Manufacturing Practice	Heat Designation	Condition	Test Temperature, deg Fahr	Tensile Strength, psi	Yield Strength (0.2 per cent Offset), psi	Elongation in 2 in., per cent	Reduction of Area, per cent
Coarse Grain	B	Stress Relieved	Room	65 500	37 000 (39 250 YP)	34	62.2
Coarse Grain	B	Stress Relieved	200	60 000	32 500	35.5	62.6
Coarse Grain	B	Stress Relieved	400	72 750	34 250	24.3	48.6
Coarse Grain	B	Stress Relieved	600	75 500	28 120	25.3	49.3
Coarse Grain	B	Stress Relieved	800	57 500	26 620	39.5	70.8
Coarse Grain	B	Stress Relieved	1000	37 250	21 370	54.8	78.7
Coarse Grain	CG1	Stress Relieved	Room	61 500	34 500 (39 200 YP)	35.5	64.0
Coarse Grain	CG1	Stress Relieved	200	58 900	31 200	29.0	61.0
Coarse Grain	CG1	Stress Relieved	400	74 300	29 300	21.0	50.0
Coarse Grain	CG1	Stress Relieved	600	67 600	23 300	31.5	59.0
Coarse Grain	CG1	Stress Relieved	800	51 200	22 700	39.5	73.0
Coarse Grain	CG1	Stress Relieved	1000	31 800	18 000	54.0	83.0
Coarse Grain	CG2	Stress Relieved	Room	64 300	36 700 (40 300 YP)	34.5	63.0
Coarse Grain	CG2	Stress Relieved	200	62 100	33 200	27.5	61.0
Coarse Grain	CG2	Stress Relieved	400	74 800	31 400	20.0	49.0
Coarse Grain	CG2	Stress Relieved	600	71 300	25 000	30.0	58.0
Coarse Grain	CG2	Stress Relieved	800	54 700	24 900	36.5	68.5
Coarse Grain	CG2	Stress Relieved	1000	34 500	20 400	50.0	80.5
Fine Grain	I	Stress Relieved	Room	64 500	38 000	40.0	66.1
Fine Grain	I	Stress Relieved	200	60 500	36 500	33.5	64.7
Fine Grain	I	Stress Relieved	400	61 000	32 000	32.0	56.5
Fine Grain	I	Stress Relieved	600	61 500	28 500	33.0	60.3
Fine Grain	I	Stress Relieved	850	42 000	26 750	21.5	64.7
Fine Grain	I	Stress Relieved	1000	29 750	23 500	39.5	60.3
Fine Grain	I	As Rolled	Room	65 600	37 600	34.0	65.0
Fine Grain	I	As Rolled	200	60 900	35 400	31.0	63.5
Fine Grain	I	As Rolled	400	66 200	34 000	23.0	53.5
Fine Grain	I	As Rolled	600	69 000	28 800	30.0	59.0
Fine Grain	I	As Rolled	800	55 100	26 800	35.5	70.0
Fine Grain	I	As Rolled	1000	35 700	21 100	44.0	69.5
Fine Grain	FG1	Stress Relieved	Room	64 600	35 000	34.0	58.5
Fine Grain	FG1	Stress Relieved	200	60 000	35 000	33.5	57.0
Fine Grain	FG1	Stress Relieved	400	59 400	28 800	28.5	59.0
Fine Grain	FG1	Stress Relieved	600	59 000	26 500	30.0	59.5
Fine Grain	FG1	Stress Relieved	800	52 400	23 900	40.0	70.5
Fine Grain	FG1	Stress Relieved	1000	34 700	20 300	40.0	58.5
Fine Grain	FG1	As Rolled	Room	66 200	33 000	35.0	60.0
Fine Grain	FG1	As Rolled	200	61 300	30 200	32.0	55.5
Fine Grain	FG1	As Rolled	400	68 500	30 000	23.0	54.0
Fine Grain	FG1	As Rolled	600	68 700	29 200	27.0	51.0
Fine Grain	FG1	As Rolled	800	55 900	26 800	35.0	65.0
Fine Grain	FG1	As Rolled	1000	35 700	22 500	40.0	70.0
Fine Grain	FG2	Stress Relieved	Room	65 600	36 800	32.5	61.0
Fine Grain	FG2	Stress Relieved	200	61 100	34 400	33.0	63.0
Fine Grain	FG2	Stress Relieved	400	60 500	31 700	28.5	60.5
Fine Grain	FG2	Stress Relieved	600	60 300	26 300	29.0	61.5
Fine Grain	FG2	Stress Relieved	800	54 000	25 800	40.0	69.5
Fine Grain	FG2	Stress Relieved	1000	37 100	20 600	37.0	56.5

TABLE III.—*Concluded.*

Type of Manufacturing Practice	Heat Designation	Condition	Test Temperature, deg Fahr	Tensile Strength, psi	Yield Strength (0.2 per cent Offset), psi	Elongation in 2 in., per cent	Reduction of Area, per cent
Fine Grain........	FG2	As Rolled	Room	65 700	37 600	34.0	62.0
Fine Grain........	FG2	As Rolled	200	62 400	35 600	31.0	61.0
Fine Grain........	FG2	As Rolled	400	66 800	31 600	24.5	57.0
Fine Grain........	FG2	As Rolled	600	67 400	29 100	28.0	57.0
Fine Grain........	FG2	As Rolled	800	56 200	27 500	36.0	65.5
Fine Grain........	FG2	As Rolled	1000	36 700	22 600	44.0	63.0

Tensile requirements for A 201, Grade B: Tensile strength, 60,000 to 72,000 psi; yield point 32,000 psi min; elongation in 2 in, 26 per cent min.

the stress-relieved condition. By contrast, the three plate heats made to fine-grain practice (I, FG1, and FG2, Figs. 3, 4, and 5) show little or no strain aging when tested in the same condition.

As a supplement to this program, the U. S. Steel Research and Development Laboratory carried out tension tests and chemical analyses for nitrogen[4] on as-rolled material from all of the plate heats made to fine-grain practice. This was done because the seamless pipe steel heats, which were in the as-rolled condition, showed an appreciable rise in tensile strength at 400 to 600 F even though some were made by fine-grain practice, and it was desired to determine whether the plate heats made to fine-grain practice would behave in a similar fashion if tested in the as-rolled condition.

U. S. Steel[5] offered the following comment:

> "If aluminum is added to the steel and the steel is then treated so that the aluminum combines with the nitrogen to form aluminum nitride (AlN), the sensitivity to strain aging is reduced, or, by certain criteria, removed. In the as-rolled condition, steels high in aluminum frequently exhibit strain-aging sensitivity because the aluminum has not combined with the nitrogen to form AlN. A treatment such as normalizing, however, favors the formation of AlN, thus reducing the amount of free nitrogen in the steel and reducing strain sensitivity. There is reason to believe that stress relieving at 1150 F may also favor the formation of AlN, thus causing the behavior observed."

This subject has been discussed in recent papers by Leslie and Rickett (**3**) and Enzian (**4**).

It is apparent from Figs. 3, 4, and 5 that stress relieving at 1150 F did indeed suppress the strain aging of the plate heats made to fine-grain practice (aluminum deoxidized); the mechanism by which the strain aging was suppressed is disclosed by the nitrogen analysis (Table I). In the as-rolled condition, very little of the total nitrogen was tied up as aluminum nitride, but in the stress-relieved condition, a substantial portion of the nitrogen was combined in this form and was therefore not available to produce strain aging. In the heats made to coarse-grain practice, however, there was insufficient aluminum to combine with the nitrogen, and thus these heats showed a strong strain-aging tendency (Fig. 2),

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[4] The total nitrogen content was determined by the wet chemical method (millings dissolved in perchloric acid, solution neutralized, ammonia distilled off, ammonia content of distillate determined using Nessler's reagent). The nitrogen as aluminum nitride was determined by the Beeghly method (**2**).

[5] Private communication from R. W. Vanderbeck, U. S. Steel Corp.

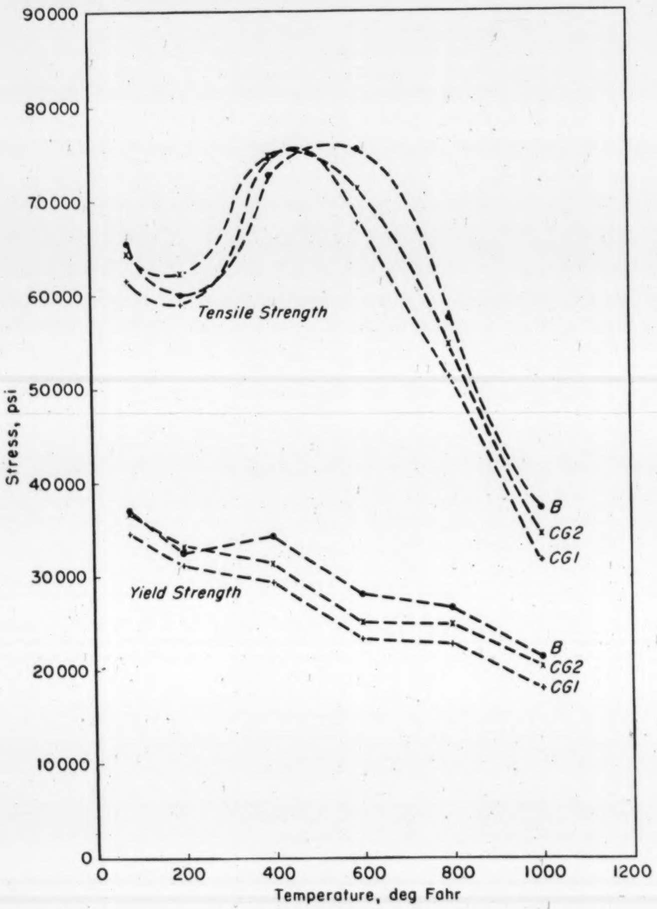


FIG. 2.—Tensile and Yield Strength of Carbon Steel Plate Made to Coarse-Grain Practice, Stress Relieved 2 hr at 1150 F.

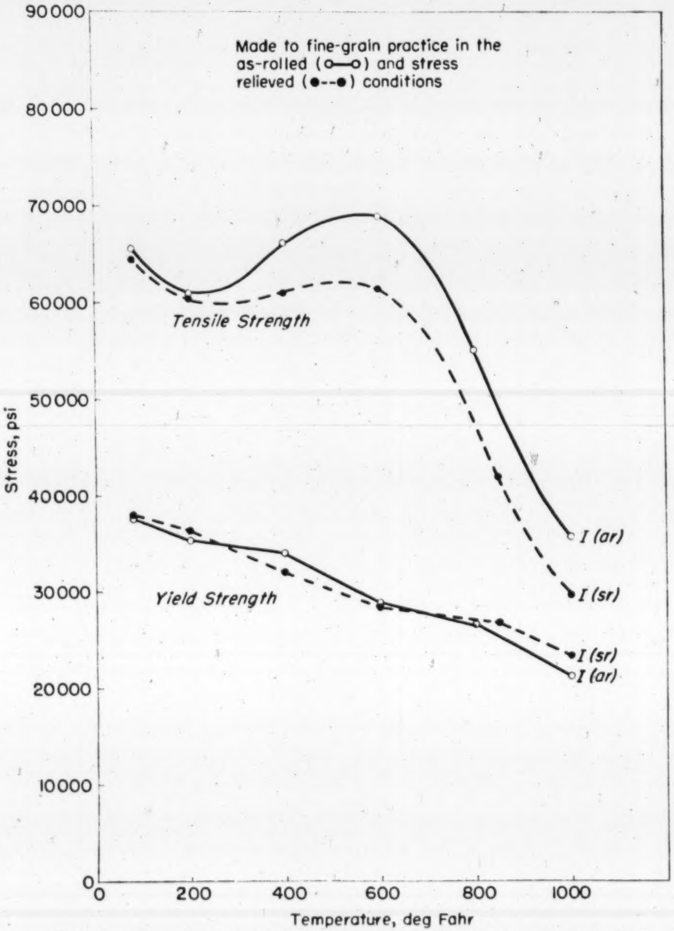


FIG. 3.—Tensile and Yield Strength of Carbon Steel Plate I.

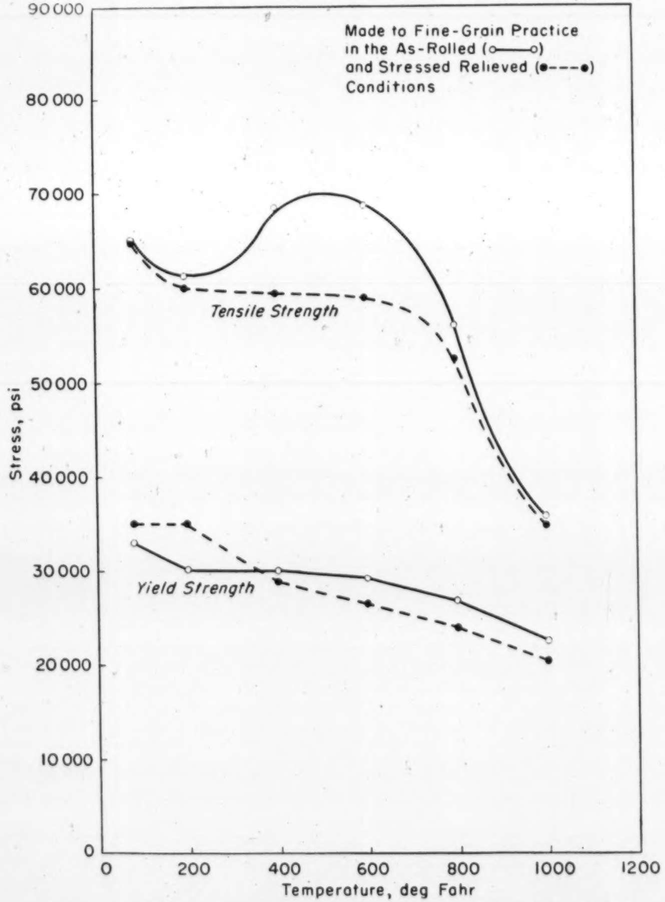


FIG. 4.—Tensile and Yield Strength of Carbon Steel Plate FG1.

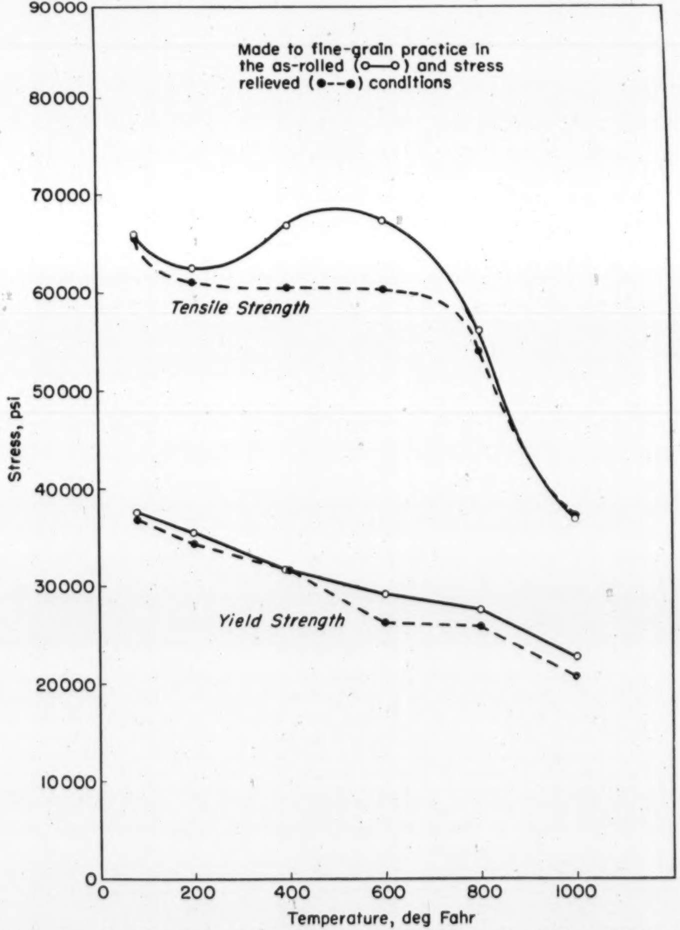


FIG. 5.—Tensile and Yield Strength of Carbon Steel Plate FG2.

even in the stress-relieved condition. At 800 and 1000 F, the tensile strengths of the stress-relieved heats made to coarse-grain practice and of the stress-relieved and as-rolled heats made to fine-grain practice are similar.

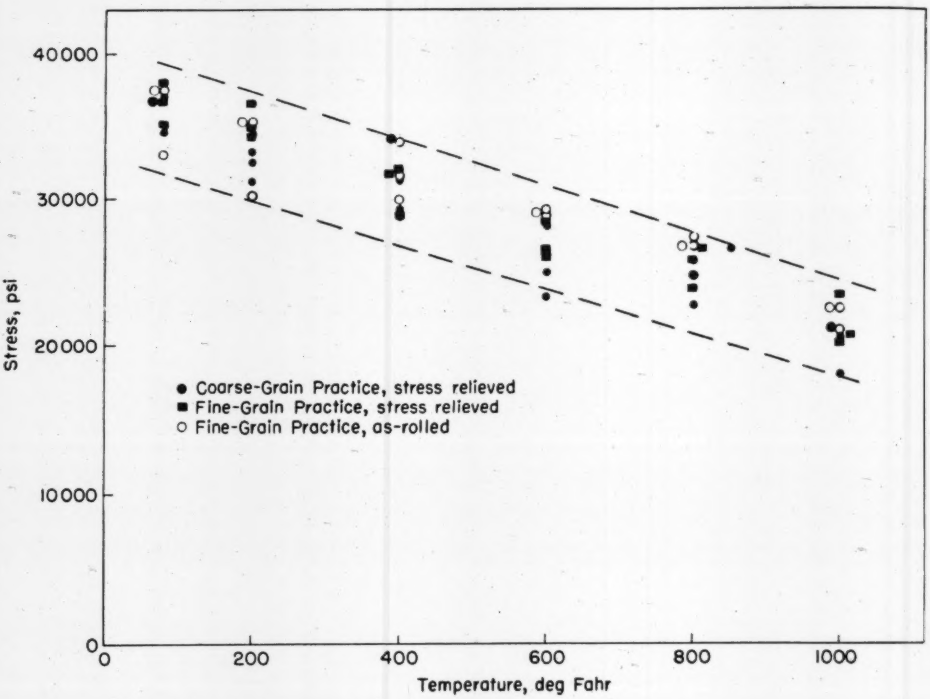


FIG. 6.—Yield Strength (0.2 per cent Offset) of Carbon Steel Plate.

Yield Strength:

Stress relieving appeared to have little effect on the yield strength, which declined uniformly from room temperature to 1000 F (Figs. 2, 3, 4, and 5). It would not be expected that strain aging would be apparent in the yield strength data, since only 0.2 per cent plastic strain is involved in its determination. For the sake of comparison, all of the yield strength data for the plate heats are plotted in Fig. 6.

At 800 and 1000 F, the plate heats made to fine-grain practice show generally similar behavior in the stress-relieved condition, except for heat I (Table III). In this material, stress-relieving results in the lowest tensile strength but the highest yield strength in the temperature range 800 to 1000 F. A possible reason for this behavior may be in the difference in deoxidation practice; FG1 and FG2 were given a final deoxidation with aluminum, whereas for heat I, ferro-carbon titanium was employed in addition to aluminum.

Ductility:

The ductility (elongation and reduction of area) of the plate heats is shown in Table III. From these data, it appears that there is only a slight decrease in ductility in the blue-brittle range for the stress-relieved heats made by fine-grain practice, which show no strain aging.

The decrease is quite pronounced, however, for those materials that do show strain aging, and is greatest for the heats made to coarse-grain practice. The ductility of these coarse-grain practice heats is slightly greater at 800 F and appreciably greater at 1000 F than that of the heats made to fine-grain practice. It is interesting to note that at 1000 F the stress-relieved fine-grain practice heats have the lowest ductility although they are the least susceptible to strain-aging in the 400 to 600 F temperature range.

TABLE IV.—RESULTS OF RUPTURE TESTS AT 1000 F ON PLATE STEEL HEATS STRESS-RELIEVED 2 HR AT 1150 F.

Type of Manufacturing Practice	Heat Designation	Stress, psi	Time to Rupture, hr	Elongation in 1 in. at Rupture, per cent	Reduction of Area at Rupture, per cent	Minimum Creep Rate, per cent per hr	Ratio of Elongation at Rupture to Time of Rupture
Coarse Grain.........	B	21 000	6.3	...	...	3.03	...
Coarse Grain.........	B	16 000	26.4	...	...	0.57	...
Coarse Grain.........	B	11 000	392	...	...	0.093	...
Coarse Grain.........	B	9 000	2504	...	...	0.0037	...
Coarse Grain.........	B	7 500	5280	...	...	0.00093	...
Coarse Grain.........	CG1	20 000	6	73	83	3.45	12.2
Coarse Grain.........	CG1	15 000	47	78	85	0.31	1.62
Coarse Grain.........	CG1	12 000	195	81	83	0.0045	0.42
Coarse Grain.........	CG1	10 000	500	81	81	0.016	0.163
Coarse Grain.........	CG1	7 000	2650	[a]	60	0.0011	[a]
Coarse Grain.........	CG2	25 000	2	65	78	9.42	32.5
Coarse Grain.........	CG2	20 000	14	69	80	1.35	4.93
Coarse Grain.........	CG2	15 000	76	78	82	0.144	1.03
Coarse Grain.........	CG2	10 000	850	77	73	0.012	0.091
Coarse Grain.........	CG2	8 000	2650	76	69	0.0014	0.029
Fine Grain...........	I	25 000	0.33	...	...	40.0	...
Fine Grain...........	I	20 000	4.7	37.7	...	0.33	8.03
Fine Grain...........	I	15 000	68.6	39.0	...	0.0188	0.568
Fine Grain...........	I	10 000	1155	40.0	...	0.0016	0.0347
Fine Grain...........	I	9 000	2035	36.9	...	0.0010	0.0185
Fine Grain...........	I	8 000	5637	27.7	...	0.00028[b]	0.00492
Fine Grain...........	FG1	30 000	0.12	42.0	58.4	160.0	350.0
Fine Grain...........	FG1	24 500	0.90	31.5	45.7	15.7	35.0
Fine Grain...........	FG1	20 000	6.75	38.5	45.2	2.34	5.70
Fine Grain...........	FG1	15 000	83.2	46.5	49.2	0.187	0.559
Fine Grain...........	FG1	12 500	289	39.5	47.0	0.0516	0.137
Fine Grain...........	FG1	10 000	1150	39.0	38.3	0.0113	0.0339
Fine Grain...........	FG1	9 000	2509	21.0	31.2	0.00620	0.00837
Fine Grain...........	FG1	7 000	9636	20.0	28.0	0.00193	0.00208
Fine Grain...........	FG2	30 000	0.13	42.5	56.8	154.0	327.0
Fine Grain...........	FG2	24 500	1.57	35.0	44.6	9.6	22.3
Fine Grain...........	FG2	20 000	8.2	38.5	46.8	1.88	4.70
Fine Grain...........	FG2	15 000	71.0	43.5	52.5	0.200	0.613
Fine Grain...........	FG2	12 500	266.7	48.5	50.1	0.0534	0.181
Fine Grain...........	FG2	10 000	1171	31.5	40.9	0.00933	0.0269
Fine Grain...........	FG2	9 000	2078	32.6	35.1	0.00439	0.0157
Fine Grain...........	FG2	7 000	9240	20.0	33.0	0.00200	0.00216

[a] Gage marks obliterated by excessive scaling.
[b] Not confirmed by check creep tests.

Rupture Strength:

The results of the rupture tests of the stress-relieved plate heats are shown in Table IV and in Fig. 7. There appears to be no distinguishable difference in the rupture strength of the heats made to coarse-grain and fine-grain practice, at least out to a rupture time of 10,000 hr. The average rupture strength of these materials for different time periods is shown in Table V.

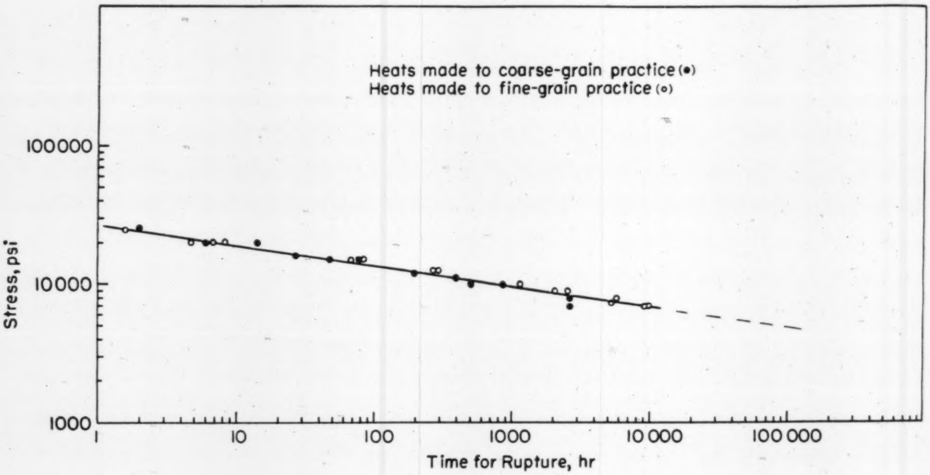


FIG. 7.—Rupture Strength of Carbon Steel Plate 1000 F.

One other point of some importance will be noted from examination of the rupture data in Table IV. Here again, as in the tensile data, it is evident that at 1000 F, the ductility of the plate heats made to coarse-grain practice is much greater than that of the heats made to fine-grain practice. No reason for this difference in behavior is obvious from the data available.

Creep Strength:

Creep data for these heats were obtained from the rupture tests (Table IV) and from the low-stress creep tests (Table VI) that were carried out by Bethlehem Steel Co. and the U. S. Steel Research Laboratory at Kearny, N. J. The results are plotted in Fig. 8.

The creep data from the rupture tests show little difference between the behavior of the heats made to coarse-grain and fine-grain practice. However, the low-stress creep tests show that, at the low creep rates, the heats made with no aluminum (coarse-grain practice) have a marked superiority to the heats deoxidized with aluminum (fine-grain practice). The average creep strengths of these materials at selected creep rates are shown in Table VII. At very low creep rates, there were insufficient data to permit a measurement of the stress for a creep rate of 0.00001 per cent per hr

TABLE V.—RUPTURE STRENGTH OF STRESS-RELIEVED PLATE STEEL AT 1000 F.

Time for Rupture, hr	Average Stress for Rupture, psi
1	27 500
10	19 500
100	14 000
1 000	10 000
10 000	7 000
100 000[a]	4 900

[a] Extrapolated.

TABLE VI.—RESULTS OF CREEP TESTS ON PLATE STEEL HEATS AT 1000 F.

Type of Manufacturing Practice	Heat Designation	Stress, psi	Duration, hr	Creep Rate, per cent per hr
Coarse Grain	B	2 500	2100	0.000020
Coarse Grain	CG1	3 500	2650	0.000021
Coarse Grain	CG1	4 000	3000	0.000036
Coarse Grain	CG1	6 000	3000	0.000275
Coarse Grain	CG2	3 500	2650	0.000010
Coarse Grain	CG2	4 000	3000	0.000031
Coarse Grain	CG2	6 000	3000	0.000177
Fine Grain	I	2 500	2400	0.00024
Fine Grain	I	2 500	1700	0.00023
Fine Grain	I	2 500	1700	0.00028
Fine Grain	FG1-A	3 500	2300	0.00031
Fine Grain	FG1-B	3 500	2000	0.00025
Fine Grain	FG1-C	2 000	2000	0.00011
Fine Grain	FG2	3 500	2500	0.00025

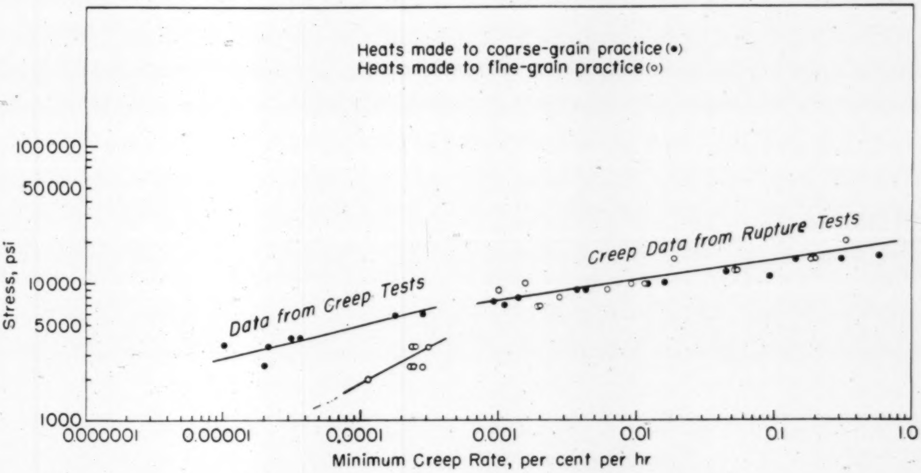


FIG. 8.—Creep Strength of Carbon Steel Plate 1000 F.

(1 per cent per 100,000 hr) in the steels made to fine-grain practice, but extrapolation of the available data indicated that it was less than 1000 psi. The fact that the aluminum-killed steels have lower creep strengths than the silicon-killed steels is in agreement with the findings of previous investigators(5, 6).

Scaling:

Several of the investigators reported that the carbon-steel creep and rupture

TABLE VII.—CREEP STRENGTH OF STRESS-RELIEVED PLATE STEEL AT 1000 F.

Type Practice	Average Stress, Creep Rate of 0.0001 per cent per hr (1 per cent per 10,000 hr), psi	Average Stress, Creep Rate of 0.00001 per cent per hr (1 per cent per 100,000 hr), psi
Coarse grain	4800	2800
Fine grain	2000	less than 1000 (extrapolation)

TABLE VIII.—CHEMICAL COMPOSITION, GRAIN SIZE, AND FINAL DEOXIDATION PRACTICE OF SEAMLESS PIPE STEEL HEATS.

Type of Manufacturing Practice	Heat Designation	Chemical Composition, per cent								Ferrite Grain Size, ASTM Number	McQuaid Ehn Grain Size, ASTM Number	Size of Pipe	Austenite Grain-Coarsening Temperature, deg Fahr	Ladle Deoxidation
		Carbon	Manganese	Phosphorus	Sulfur	Silicon	Total Aluminum	Aluminum Oxide	Total Nitrogen					
Fine grain.......	No. 1	0.29	0.64	0.014	0.025	0.13	0.031	0.003	0.006	[a]	6–8	10⅝ in. OD × 0.843 in. wall	1700–1800	3.2 lb per ton Si (50 per cent Fe-Si) and 1.8 lb per ton Al
Fine Grain.......	No. 2	0.27	0.43	0.012	0.026	0.16	0.029	0.006	0.005	4–6 Widmanstätten	6–8	8⅝ in. OD × 0.906 in. wall	1700–1800	6.2 lb per ton of 50 per cent Fe-Si and 1.4 lb per ton Al
Coarse grain.....	No. 3	0.26	0.77	0.011	0.022	0.20	0.007	0.002	0.003	7–8	3–5	8⅝ in. OD × 0.906 in. wall	1600–1700	8.4 lb per ton of 50 per cent Fe-Si, 0.6 lb per ton Al, and 2.0 lb of 50 per cent Fe-C-Ti

Chemical composition of A 106 Grade B: 0.30 carbon, 0.29 to 1.06 manganese, 0.048 max phosphorus, 0.058 max sulfur, 0.10 min silicon.

[a] Ferrite grain size could not be determined because of strong Widmanstätten pattern.

specimens, tested in air at 1000 F, showed considerable scaling.

SEAMLESS CARBON PIPE STEEL

The composition of the seamless carbon pipe steel heats (A 106, Grade B) is shown in Table VIII together with the grain-size characteristics and the final ladle deoxidation. Three heats of the pipe steel were tested, two made to fine-grain practice and one made to coarse-grain practice. Test samples were taken longitudinally from heavy-wall seamless pipe (pipe sizes were $10\frac{5}{8}$-in. outside diameter by 0.843-in. wall and $8\frac{5}{8}$-in. outside diameter by 0.906-in. wall. See Table VIII).

TABLE IX.—AUSTENITE GRAIN-COARSENING CHARACTERISTICS OF PIPE STEEL HEATS.

Type of Manufacturing Practice	Heat Designation	Austenite Grain Size[a] After 60 min at Various Temperatures				
		1600 F	1700 F	1800 F	1900 F	2000 F
Fine Grain	1	6	5–6	2–5	2–4	1–3
Fine Grain	2	6–7	5–6	3–4	3–4	2–3
Coarse Grain	3	6	1–3	1–2	2–3	2–3

[a] ASTM grain size number.

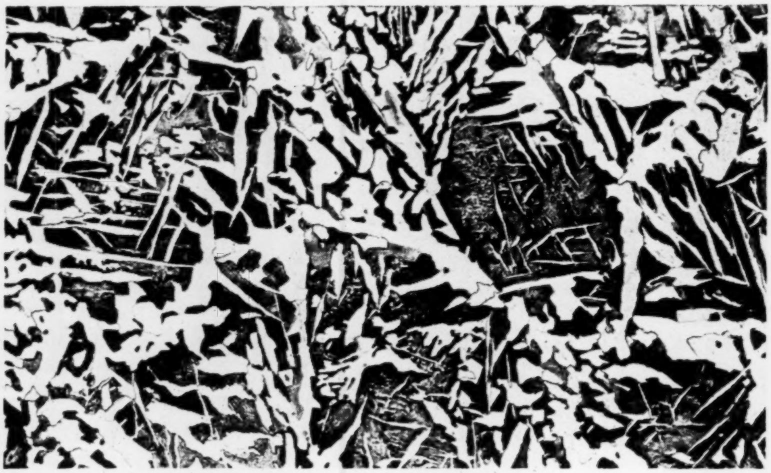
Austenite Grain-Coarsening Characteristics:

The austenite grain-coarsening characteristics were determined by the Youngstown Sheet and Tube Co. employing the gradient-quench method in the same manner as for the plate steel. The results of these tests on the pipe heats are shown in Table IX. It will be noted that the pipe heats behaved in the same manner as the plate heats; the heat made to coarse-grain practice coarsened between 1600 and 1700 F, while the heats made to fine-grain practice coarsened at a higher temperature –between 1700 and 1800 F.

As in the plate heats, the difference in grain-coarsening characteristics was not reflected in the actual microstructure (Fig. 9). There was, however, considerable difference in the actual microstructure and ferrite grain size of the pipe heats. The two heats made to fine-grain practice had a rather coarse ferrite grain size in a Widmanstätten pattern, while the heat made to coarse-grain practice had a rather fine ferrite grain size and no evidence of a Widmanstätten pattern. It thus appears, even more clearly than in the case of the plate steel, that the actual microstructure is determined by the hot-working practice employed for the pipe, rather than by the austenite grain-coarsening temperature. The two heats made to fine-grain practice must have been finished quite hot (1700 to 1800 F or above), while the heat made to coarse-grain practice was finished at a lower temperature (reported to be 1400 to 1600 F).

Tensile Strength:

The tensile strength of the pipe heats is given in Table X and the results are plotted in Figs. 10, 11, and 12. As discussed above, the original plans for this investigation called for testing the pipe steel in the as-rolled condition. When it was found, however, that the as-rolled pipe steels made by fine-grain practice exhibited strain aging at 400 to 600 F in the tension test, whereas the stress-relieved plate steels did not, supplementary tests were conducted to investigate the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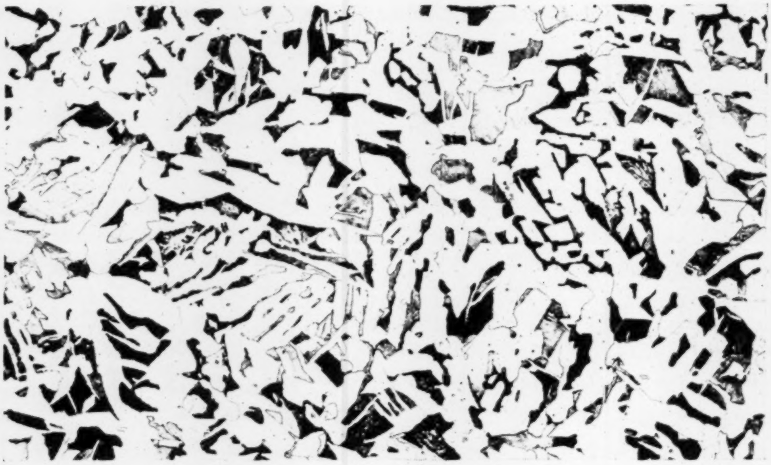
Grain
Practice


Fine-
Grain
Practice

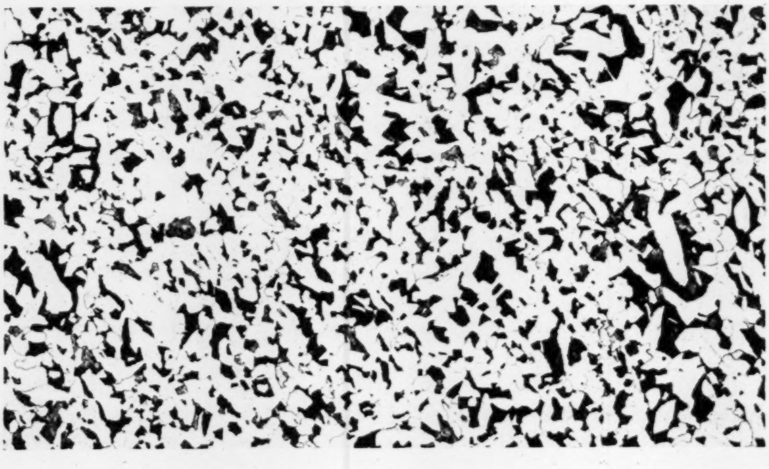

Coarse-
Grain
Practice

FIG. 9.—Microstructure of Pipe Steel Heats—Nital Etch (× 100).

TABLE X.—TENSION TEST RESULTS FOR SEAMLESS PIPE STEEL HEATS.

Type of Manufacturing Practice	Heat Designation	Condition	Test Temperature, deg Fahr	Tensile Strength, psi	Yield Strength (0.2 per cent offset), psi	Elongation in 2 in., per cent	Reduction of area, per cent
Fine Grain........	1	As Rolled	Room	71 400	35 000	35.0	57.9
Fine Grain........	1	As Rolled	200	68 750	35 380	24.5	56.0
Fine Grain........	1	As Rolled	400	81 750	35 950	16.5	41.1
Fine Grain........	1	As Rolled	600	78 250	30 000	30.5	50.0
Fine Grain........	1	As Rolled	800	59 150	28 250	35.5	60.1
Fine Grain........	1	As Rolled	1000	35 050	24 880	44.0	55.2
Fine Grain........	1	Stress Relieved[a]	Room	68 800	36 500	35.0	58.1
Fine Grain........	1	Stress Relieved[a]	200	63 800	34 000	31.0	55.8
Fine Grain........	1	Stress Relieved[a]	400	65 900	29 100	31.0	52.1
Fine Grain........	1	Stress Relieved[a]	600	64 600	27 600	37.0	60.6
Fine Grain........	2	As Rolled	Room	67 800	33 100	32.0	57.2
Fine Grain........	2	As Rolled	200	65 400	35 200	24.0	52.4
Fine Grain........	2	As Rolled	400	77 400	33 900	18.0	43.0
Fine Grain........	2	As Rolled	600	66 600	27 900	36.0	59.9
Fine Grain........	2	As Rolled	800	47 900	26 800	32.5	59.5
Fine Grain........	2	As Rolled	1000	27 700	18 200	40.0	59.4
Fine Grain........	2	Stress Relieved[a]	Room	59 700	28 900	36.0	59.6
Fine Grain........	2	Stress Relieved[a]	200	54 800	26 100	32.0	64.0
Fine Grain........	2	Stress Relieved[a]	400	61 000	23 000	32.0	58.8
Fine Grain........	2	Stress Relieved[a]	600	57 100	23 500	31.0	61.8
Coarse Grain......	3	As Rolled	Room	72 000	37 500	38.5	59.5
Coarse Grain......	3	As Rolled	200	67 600	34 000	31.5	60.3
Coarse Grain......	3	As Rolled	400	75 050	34 500	21.0	48.2
Coarse Grain......	3	As Rolled	600	73 800	31 000	36.0	59.3
Coarse Grain......	3	As Rolled	800	57 000	30 250	40.0	76.0
Coarse Grain......	3	As Rolled	1000	33 200	23 250	59.5	80.7
Coarse Grain......	3	Stress Relieved[a]	Room	68 500	39 500	36.0	60.6
Coarse Grain......	3	Stress Relieved[a]	200	64 900	35 000	29.0	59.1
Coarse Grain......	3	Stress Relieved[a]	400	71 900	32 500	24.0	54.2
Coarse Grain......	3	Stress Relieved[a]	600	67 400	22 000	38.0	65.7

[a] Stress relieved 2 hr at 1150 F.

Tensile requirements for A 106 Grade B: tensile strength, 60 000 psi min; yield strength (0.2 per cent) 35 000 psi min, elongation in 2 in. 22 per cent min.

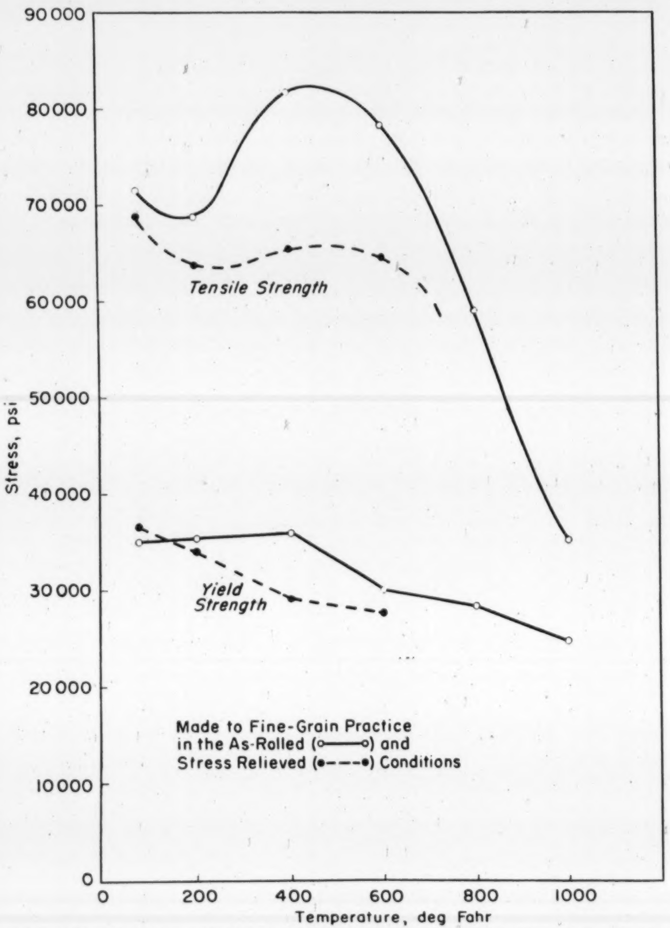


FIG. 10.—Tensile and Yield Strength of Carbon Steel Pipe Heat No. 1.

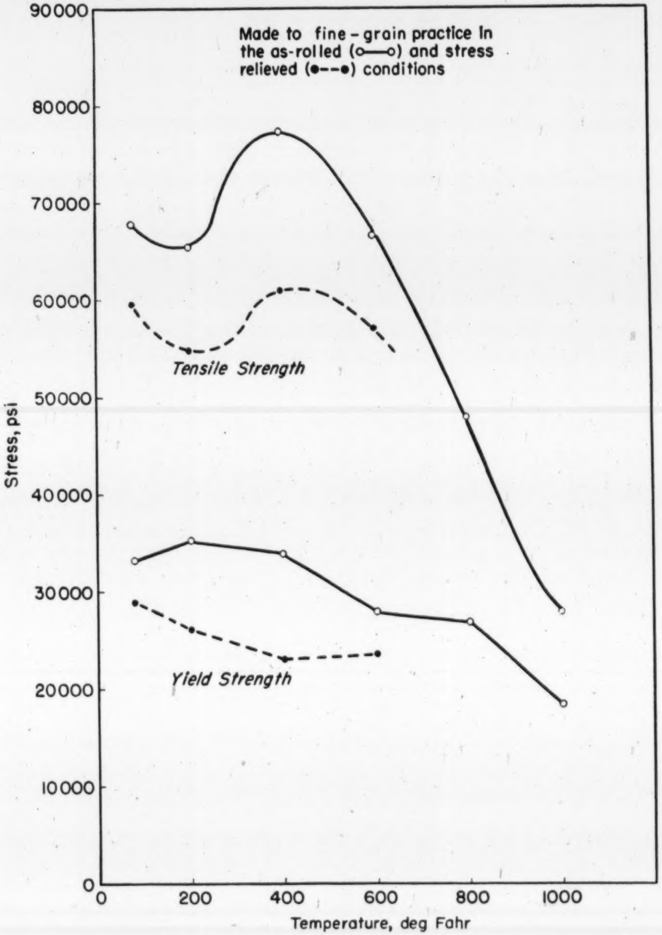


FIG. 11.—Tensile and Yield Strength of Carbon Steel Pipe Heat No. 2.

effect of stress relieving on strain-aging sensitivity. These additional tension tests on the pipe steel were carried out by the National Tube Division, United States Steel Corp., at room temperature, 200, 400, and 600 F. Data on the stress-relieved pipe heats were then compared with the data from the original tests, conducted by The Babcock & Wilcox Co., by Timken Roller Bearing Co., and by The National Tube Division, on as-rolled material.

From examination of Figs. 10, 11, and 12, it will be seen that the pipe steel follows the same pattern of behavior as the plate steel, although the differences are not as pronounced, possibly because of the smaller amount of aluminum used in the final deoxidation of the pipe heats. The amount of strain aging in the two pipe heats made to fine-grain practice is reduced by the stress-relieving treatment, but the only effect in the heat made to coarse-grain practice is a slight over-all reduction of the tensile strength. Only total nitrogen (Table VIII) was

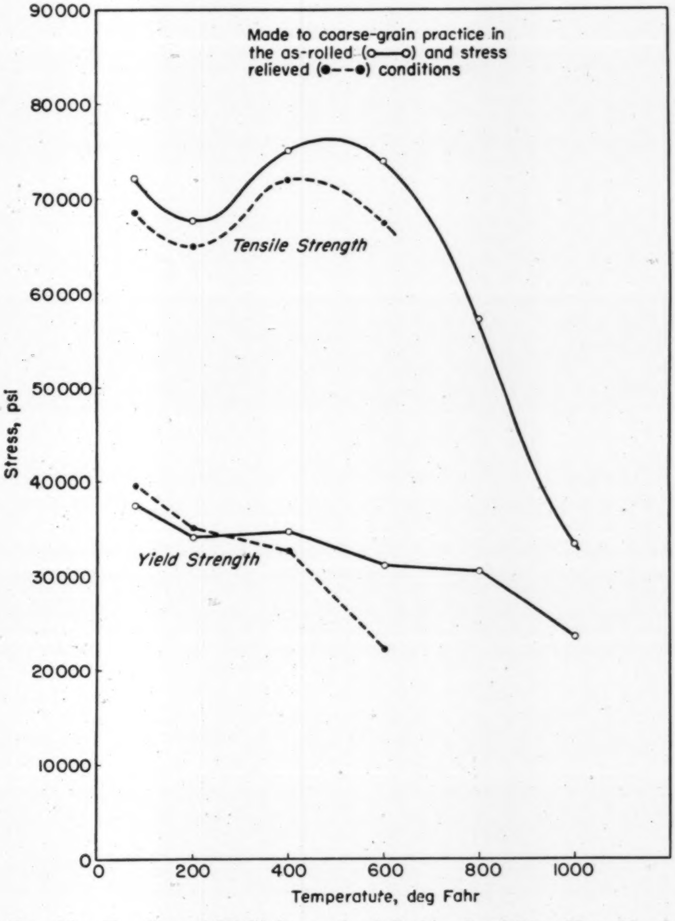


FIG. 12.—Tensile and Yield Strength of Carbon Steel Pipe Heat No. 3.

determined for the pipe steel, since the reason for the reduction of strain aging by stress relieving was believed to be the same as for the plate steel.

At 800 and at 1000 F, the tensile strength of the coarse-grain practice heat (No. 3) is comparable to that of the fine-grain practice heat No. 1. Moreover, the tensile strengths of these pipe heats and of the plate heats are comparable at 800 and at 1000 F. The tensile strength of the fine-grain practice pipe heat No. 2 is considerably lower at these temperatures, which may possibly be attributed to its lower manganese content.

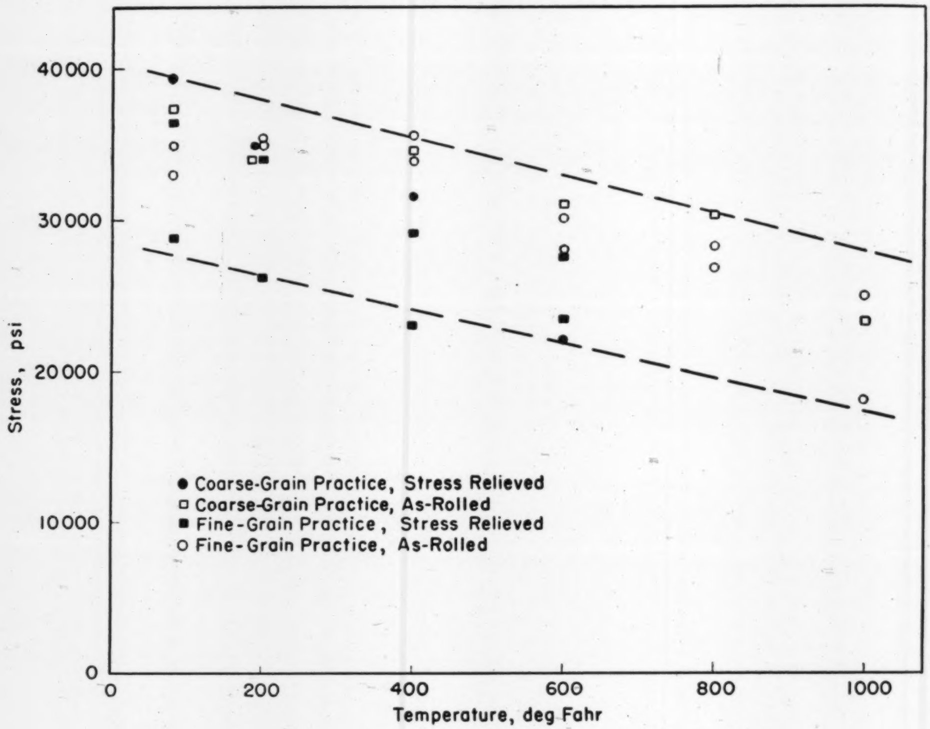


FIG. 13.—Yield Strength (0.2 per cent Offset) of Carbon Steel Pipe.

Yield Strength:

The yield strength of the pipe heats appears to decrease rather uniformly with increase of temperature. In all three heats, stress relieving appears to reduce the yield strength of the pipe steel at 400 and 600 F. For the purpose of ready comparison, all of the yield-strength data for the pipe heats are plotted in Fig. 13.

Ductility:

Confirming the trend noted in the plate steel, the ductility (elongation and reduction of area) of the pipe steel decreased slightly in the range of 200 to 600 F, and the decrease is more pronounced the greater the tendency for strain aging. Also, the ductility of the heat made to coarse-grain practice (steel 3) is greater than that of the heats made to fine-grain practice (steels 1 and 2) at 800 and 1000 F.

TABLE XI.—RESULTS OF RUPTURE TESTS AT 1000 F ON SEAMLESS PIPE STEEL HEATS (AS ROLLED).

Type of Manufacturing Practice	Heat Designation	Stress, psi	Time to Rupture, hr	Elongation at Rupture, per cent	Reduction of Area at Rupture, per cent	Minimum Creep Rate, per cent per hr	Ratio of Elongation at Rupture to Time of Rupture
Fine Grain.............	1	15 000	357.5	46.2	48.6	0.02368	0.129
Fine Grain.............	1	13 500	440.2	38.3	53.0	0.01478	0.087
Fine Grain.............	1	9 500	2189.5	43.3	61.6	0.00391	0.0197
Fine Grain.............	1	6 500	11557	40.8	55.2	0.00017	0.0035
Fine Grain.............	2	29 000	0.1	51	67.9	...	510.0
Fine Grain.............	2	28 000	0.3	47	61.5	...	156.5
Fine Grain.............	2	25 000	1.2	49	61.0	...	43.4
Fine Grain.............	2	22 000	4.5	53	57.2	...	11.8
Fine Grain.............	2	20 000	9.4	55	57.4	...	5.9
Fine Grain.............	2	17 500	23.9	40	50.0	0.580	1.68
Fine Grain.............	2	15 000	107	40	51.6	0.042	0.374
Fine Grain.............	2	13 000	405	53	61.3	0.010	0.131
Fine Grain.............	2	11 500	813	68	64.3	0.00169	0.0835
Fine Grain.............	2	10 000	1822	43	52.1	0.00286	0.0236
Fine Grain.............	2	8 900	2920	38	64.7	0.00365	0.0130
Fine Grain.............	2	8 500	3475	32	52.0	0.000897	0.0092
Fine Grain.............	2	7 000	8592	30	36.9	0.000439	0.0035
Coarse Grain...........	3	15 000	225	40.8	65.6	0.02475	0.181
Coarse Grain...........	3	13 500	725.2	40.4	56.5	0.01012	0.056
Coarse Grain...........	3	12 000	1279.6	37.4	58.8	0.00739	0.0293
Coarse Grain...........	3	9 500	3970.0	39.5	59.3	0.00271	0.00995
Coarse Grain...........	3	8 000	8852	51.3	65.0	0.00033	0.00579
Coarse Grain...........	3a[a]	18 000	85	55.0	77.7	...	0.646
Coarse Grain...........	3a[a]	15 000	251	54.0	75.6	...	0.215
Coarse Grain...........	3a[a]	11 500	572	59.4	72.8	...	0.104
Coarse Grain...........	3a[a]	9 000	3171	45.0	61.5	...	0.00142

[a] Supplementary data.

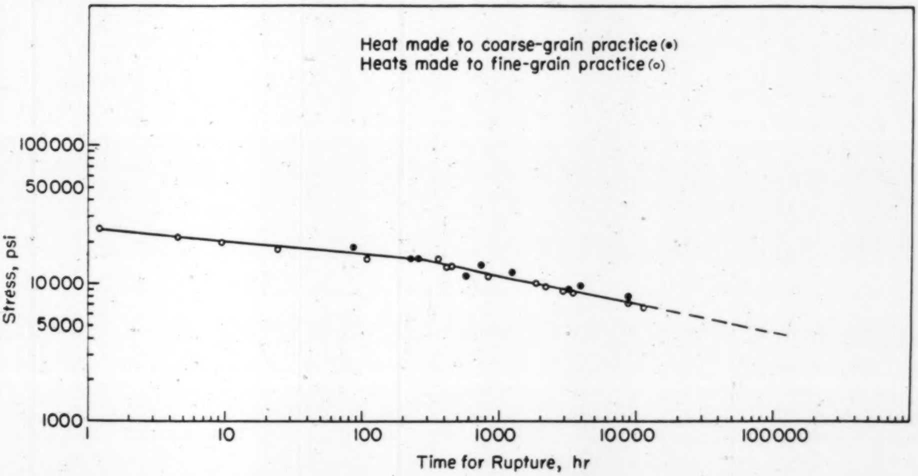


FIG. 14.—Rupture Strength of Carbon Steel Pipe 1000 F.

Rupture Strength:

The results of the rupture tests on the as-rolled pipe steel are shown in Table XI and are plotted in Fig. 14. There is no measurable difference in the rupture strength of the heats made to coarse-grain and fine-grain practice. The average rupture strengths of these materials for different time periods is given in Table XII.

TABLE XII.—RUPTURE STRENGTH OF AS-ROLLED SEAMLESS PIPE STEEL AT 1000 F.

Time for Rupture, hr	Average Stress for Rupture, psi
1	25 500
10	20 500
100	16 500
1 000	12 000
10 000	7 300
100 000[a]	4 400

[a] Extrapolated.

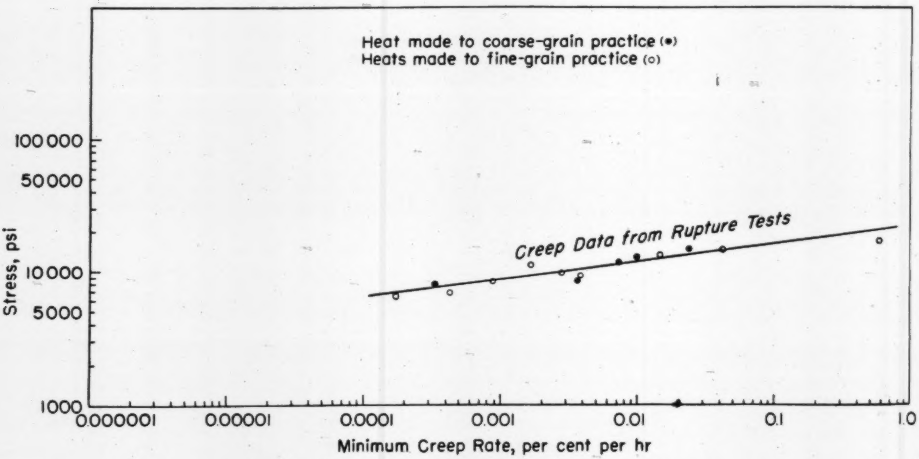


FIG. 15.—Creep Strength of Carbon Steel Pipe 1000 F.

Creep Strength:

Creep data for the three pipe heats are available only from the rupture tests; no low-stress creep tests were run on these materials. The creep data are listed in Table XI and plotted in Fig. 15. Differences between the behavior of heats made to coarse-grain and to fine-grain practice are not detectable.

COMPARISON OF CREEP AND RUPTURE STRENGTH OF PLATE STEEL AND SEAMLESS PIPE STEEL

The average creep and rupture strengths of the plate steel and the pipe steel are compared in Tables XIII and XIV.

Rupture:

The stress for rupture of the plate and pipe steels are quite similar for the 10,000 and 100,000-hr time periods (Table XIII). For shorter time periods, the pipe steel appears to be a little stronger, due to the fact that there is a definite break in the slope of the log-log plot of stress *versus* rupture time in the case of the pipe steel, while no break is apparent in the similar plot for the plate steel. The stress for rupture in 100,000 hr (4400 to 4900 psi) is well above the ASME allowable working stress of 2500 psi for carbon steel at 1000 F.

Creep:

The creep results for the plate and pipe steels are compared in Table XIV. At the rapid creep rates observed in the rupture tests, there is no significant difference between the plate and pipe steels nor between the heats made to coarse-grain and to fine-grain practice.

In the case of the plate steel, standard low-stress creep tests were carried out. It will be seen from Table XIV that the stress for a creep rate of 0.00001 per cent per hr (1 per cent per 100,000 hr) for the plate steel heats made to coarse-grain practice is 2800 psi, which is above the ASME allowable working stress of 2500 psi at 1000 F for carbon steels. However, the stress for a similar creep rate for the heats made to fine-grain practice (estimated to be less than 1000 psi) is definitely lower than the 2500 psi allowable stress. The low creep strength of the steel made to fine-grain practice agrees with previous results indicating the inferior creep strength of aluminum-killed heats at elevated temperature (**5, 6**).

TABLE XIII.—COMPARISON OF RUPTURE STRENGTH OF PLATE AND PIPE STEELS AT 1000 F.

Time for Rupture, hr	Stress for Rupture, Average	
	Plate	Pipe
1..........	27 500	25 500
10..........	19 500	20 500
100..........	14 000	16 500
1 000..........	10 000	12 000
10 000..........	7 000	7 300
100 000[a]........	4 900	4 400

[a] Extrapolated.

CONCLUSIONS

1. Confirming results obtained by previous investigators, it was found that strain aging as judged by elevated-temperature tension tests is associated with the presence of uncombined nitrogen in the steel.

2. In the as-rolled condition, the heats made to fine-grain practice were found to strain age as much as the heats made to coarse-grain practice. Strain aging was reduced or eliminated, however, in the heats made to fine-grain practice by stress relieving at 1150 F. The reheating or "stress relieving" causes an appreciable portion of the nitrogen to combine with the aluminum as aluminum nitride.

TABLE XIV.—COMPARISON OF CREEP STRENGTH OF PLATE AND PIPE STEELS AT 1000 F.

From Rupture Tests		
Creep Rate, per cent per hr	Average Creep Stress, psi	
	Plate	Pipe
0.1..............	15 000	16 000
0.01.............	11 000	11 800
0.001............	8 000	8 600

3. In general, for the same nominal composition, the tensile strengths of the plate and pipe steels are comparable at 800 and at 1000 F, whether made to fine-grain or coarse-grain practice and whether as-rolled or stress-relieved.

4. At 1000 F, the tensile ductility of the plate and pipe heats made to coarse-grain practice is appreciably higher than that of the heats made to fine-grain practice, whether they are in the as-rolled or stress-relieved condition.

5. Rupture tests at 1000 F, conducted for as long as 10,000 hr, indicate no significant difference in rupture strength between steels made to coarse-grain and to fine-grain practice when these steels are tested in the as-rolled or stress-relieved condition. Extrapolation of the data indicate a stress for rupture in 100,000 hr of 4400 to 4900 psi.

6. Creep tests indicate that at 1000 F, the plate steel heats, deoxidized with

approximately 2.5 lb of aluminum per ton, have less than half the creep strength of the heats made to coarse-grain practice. For a creep rate of 0.00001 per cent per hr (1 per cent per 100,000 hr), the average creep strength at 1000 F of the heats of plate steel made to fine-grain practice was estimated to be less than 1000 psi, as compared to 2800 psi for the heats made to coarse-grain practice.

REFERENCES

(1) J. R. Vilella, "The Grain Size of Steel," *Mechanical Engineering*, April, 1940, pp. 293–307.

(2) H. F. Beeghly, "Determination of Aluminum Nitride Nitrogen in Steel," *Analytical Chemistry*, Vol. 21, pp. 1513–1519 (1949). U. S. Patent No. 2,526,841, Oct. 24, 1950.

(3) W. C. Leslie and R. L. Rickett, "The Influence of Aluminum and Silicon Deoxidation on the Strain Aging of Low Carbon Steel," *Journal of Metals*, Am. Inst. Mining and Metallurgical Engrs., Aug., 1953, pp. 1021–1031.

(4) G. H. Enzian, "Behavior of Carbon and Low Alloy Steels Between −20 and +650 F," *Welding Journal*, Research Supplement, Vol. XVIII, No. 12, Dec., 1953, pp. 605S–618S.

(5) G. V. Smith and E. J. Dulis, "Effect of Manufacturing Practice on Creep and Creep-Rupture Strength of Low-Carbon Steel," *Proceedings*, Am. Soc. Testing Mats., Vol. 49, p. 584 (1949).

(6) R. F. Miller, "Effect of Deoxidization Practice on Creep Strength of Carbon-Molybdenum Steel at 850 F," *Transactions*, Am. Soc. Mechanical Engrs., Vol. 65, No. 4, May, 1943, pp. 309–316.

DISCUSSION

Mr. A. B. Wilder[1] (*presented in written form*).—The steels described by Mr. Miller were included in a graphitization study conducted by the National Tube Division of United States Steel Corp., and although graphitization characteristics are not discussed in the paper, our results may be of interest.

The influence of aluminum used in the deoxidation of steel in accelerating graphitization is well recognized. Experience in tubular products with Grade B carbon steel deoxidized without the use of aluminum has been limited. Recognition of this type of material on a commercial basis would require further evaluation as carbon steels used for the production of seamless pipe are usually treated in the ladle with aluminum.

The influence of small amounts of residual chromium or special alloy additions, such as nitrogen, on graphitization characteristics of steel melted to coarse-grained deoxidation practice has not been thoroughly investigated; however, the presence of these elements seems to reduce graphitization. It also is possible that special deoxidation practices may be helpful. Investigations of this nature should be conducted with material produced by the basic open-hearth process.

The steels described in Tables I and VIII were exposed at 900 and 1050 F for 10,000 hr without stress to evaluate their stability characteristics with particular reference to graphitization. Creep-rupture and other properties after exposure will be evaluated later.

Before exposing the bars, which were 1 in. square and 20 in. long, a large weld bead 6 in. long was deposited longitudinally on one side of the bar, and on the opposite side a small weld bead 6 in. long was deposited. The large weld bead represented normal welding conditions with respect to temperature gradients and the small weld bead represented severe welding conditions. An E6010 electrode was used without preheat or postheat. The welded samples were examined metallographically before and after exposure to observe the weld metal, the weld heat-affected zone, and the parent metal not affected by welding. The procedure employed has been described.[2]

Graphitization results are presented in the accompanying Table XV and were originally rated according to the procedure described by D. B. Collyer and J. O. Light.[3]

These data may be summarized as follows:

1. Graphite was not observed in the 900-F weld metal samples but was observed in four of the 1050-F weld metal samples.
2. When graphite was observed in the weld heat-affected zone, it was also observed in the parent metal not affected by welding.
3. Graphite was not observed in the coarse-grained steels after 10,000 hr ex-

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[1] Chief Metallurgist, National Tube Division, U. S. Steel Corp., Pittsburgh, Pa.

[2] A. B. Wilder and J. D. Tyson, "Graphitization of Steel at Elevated Temperatures," *Transactions*, Am. Soc. Metals, Vol. 40, p. 233 (1948).

[3] D. B. Collyer and J. O. Light, "Graphitization Rating Chart," *Metal Progress*, Vol. 55, May, 1949, p. 664-B.

TABLE XV.—OCCURRENCE OF GRAPHITE IN BEAD-WELDED STEELS AFTER 10,000-HR EXPOSURE AT TEMPERATURE.

Steel Identification	Material	Deoxidation Practice	Graphite Occurrence			
			900 F		1050 F	
			Weld Metal	Parent[a] Metal	Weld Metal	Parent[a] Metal
1...........	Pipe	Fine grain	None	Graphite	None	Graphite
2...........	Pipe	Fine grain	None	Graphite	Graphite	Graphite
3...........	Pipe	Coarse grain	None	None	Graphite	Graphite
B...........	Plate	Coarse grain	None	None	None	Graphite
I...........	Plate	Fine grain	None	Graphite	Graphite	Graphite
CG1........	Plate	Coarse grain	None	None	None	Graphite
FG1........	Plate	Fine grain	None	Graphite	Graphite	Graphite

[a] Includes weld heat-affected zone.

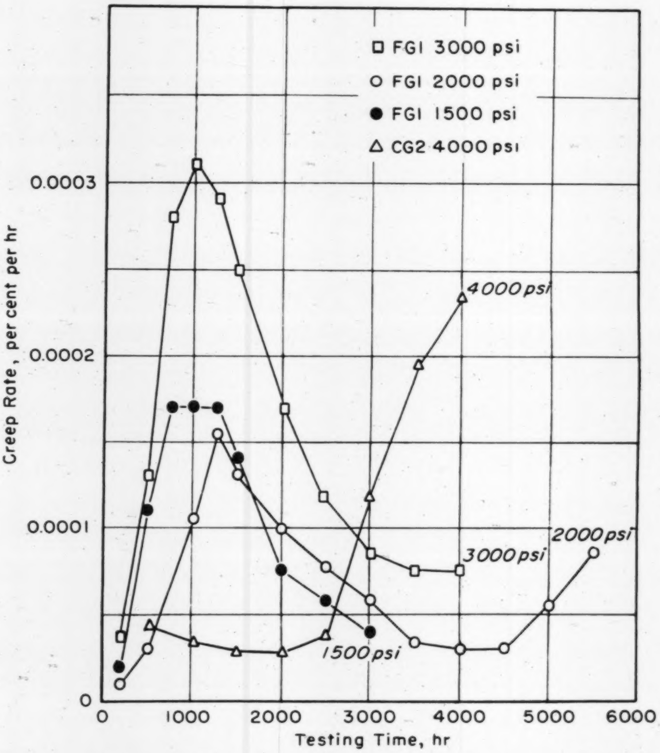

FIG. 16.—Time - Observed Creep Rates for Carbon Steel FG1 and CG2 at 1000 F.

posure at 900 F, and these steels, therefore, were less susceptible to graphitization at this temperature as compared with the fine-grained steels.

4. Graphite was observed in the fine-grained steels at 900 and 1050 F and the coarse-grained steels at 1050 F.

5. The graphitization characteristics of the pipe and plate material were similar.

MESSRS. C. DALE DICKINSON,[4] R. JACKOWSKI,[5] AND J. W. FREEMAN[5] (*presented in written form*).—Mr. Miller and the ASTM-ASME Joint Committee on the Effect of Temperature on the Properties of Metals and the Steam Power Panel of the Joint Committee are to be highly complimented for this very useful paper. The presentation of the properties of carbon steel in the form in which it is most widely used will be most helpful in evaluating this material with its rather wide variations in high-temperature properties from normal metallurgical variables.

Four long-time creep tests at 1000 F are in progress on a fine-grained (FG1) and a coarse-grained (CG2) carbon steel in the high-temperature metallurgical laboratories of the Engineering Research Institute of the University of Michigan. These tests were undertaken to extend the creep data presented in Mr. Miller's paper. The results of these creep tests are presented in the accompanying Fig. 16 in the form of creep rate - time curves. It will be noted from these curves that the creep rate - time relationships are by no means simple. All three of the FG1 samples underwent an increase in creep rate during the first 1000 to 1500 hr of testing followed by about 2500 hr of decreasing creep rate. The creep rate of the 2000-psi test began to increase again after 4500 hr. The test on CG2 material had a normal creep curve out to about 2000 hr; however, between 2000 and 2500 hr the creep rate increased rapidly, although it will be noted that there is some indication of the creep rate slowing down again at about 4000 hr. The reason for these unusual creep rate - time relations has not been established by the work in progress.

It will be noted from the accompanying Fig. 17 that the minimum creep rates for the FG1 material fit reasonably well on the log stress - log creep rate curve for that material for the tests reported by Mr. Miller. Also the minimum creep rate reported for the material CG2 checks very closely with the material reported in Mr. Miller's paper.

The rupture strengths for both the coarse- and fine-grained materials were very nearly the same. The probability is that the coarse-grained material had more elongation at fracture than the fine-grained material. The situation, therefore, is that both materials have about the same rupture strength, but with the fine-grained material having a much lower creep strength, indicated by Fig. 17, and less total elongation to fracture. This indicates that in all probability the coarse-grained material should enter third-stage creep before the fine-grained material in order to rationalize the diverse creep and ductility characteristics for equal rupture strengths. The time - creep rate curves shown in Fig. 16 appear to bear this out. However, it is doubtful that the answer is as simple as this, inasmuch as the creep rates under the 2000- and 4000-psi stresses for the FG1 and CG2 materials, respectively, could not continue to increase as indicated by

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[4] Research Metallurgist, Research Laboratories, Allis-Chalmers Manufacturing Co., Milwaukee, Wis.

[5] Research Assistant and Research Engineer, respectively, Engineering Research Institute, University of Michigan, Ann Arbor, Mich.

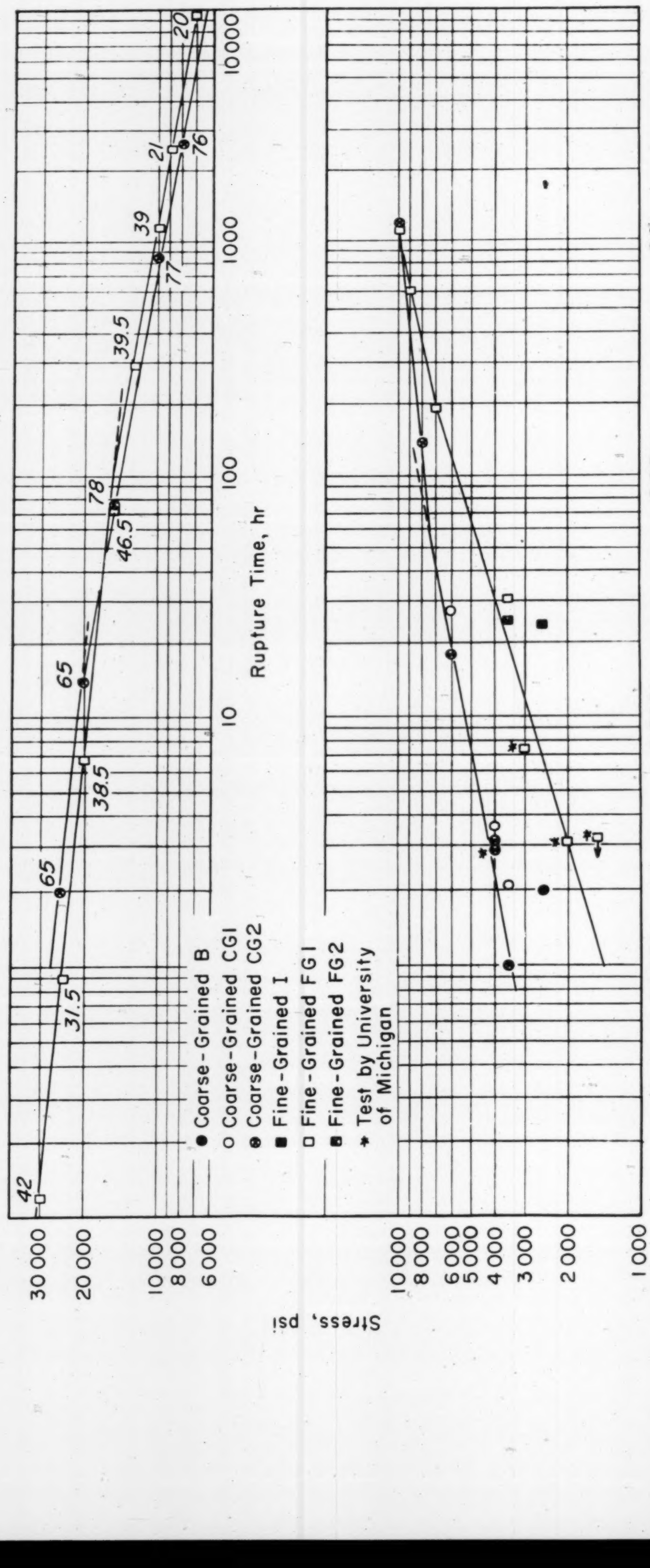

FIG. 17.—Stress-Rupture Time and Stress-Creep Rate Curves at 1000 F for Carbon Steel Plate Materials. All samples as rolled plus 1150 F for 2 hr. Except as indicated, all data from Miller's paper.

Fig. 16 and still have the extremely long rupture life predicted by the extrapolation of the stress - rupture - time curves. It therefore appears quite certain that continued testing should again show a decrease in creep rate for both materials. It is our feeling that structural changes may still be occurring in these materials under the test conditions covered by the curves of Fig. 16. Therefore, the creep tests will have to be continued for a longer period of time to establish a true secondary creep rate if one exists.

MR. D. L. NEWHOUSE[6] (*by letter*).—Mr. Miller's paper made a distinct contribution to a better understanding of the properties of carbon steel for elevated-temperature service, as currently made and used.

Examination of the data presented in the paper reveals two rather striking features. The first is the close agreement of long-time rupture strength data for all of the steels tested, in spite of differences in source, melting practice, form, and treatment; the second is the divergence in creep data presented, particularly between those obtained from high stress - rupture tests and low stress - creep tests and especially for steels made by fine-grain practice. To illustrate this, creep data from the rupture tests on fine-grain practice plate steel heats from Table IV and on fine-grain practice pipe steel heats from Table XI have been plotted in the accompanying Fig. 18, for comparison with the low stress-creep test data on fine-grain plate steels from Table VI. As can be seen, the lowest stressed rupture tests from three heats produced creep rates comparable to those obtained by the creep tests at more than double the stress level of the latter.

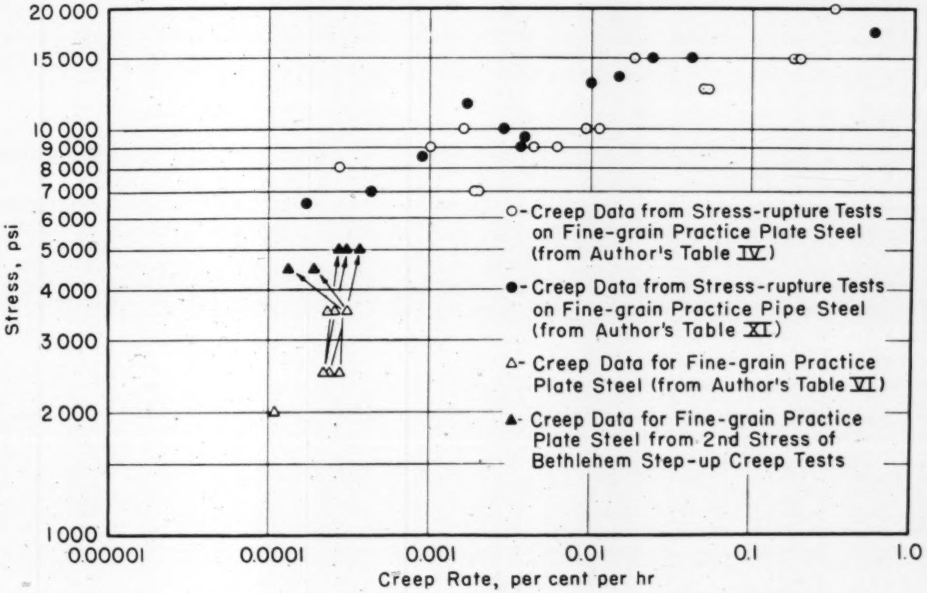

FIG. 18.—Creep Strength of Fine-Grain Practice Plate and Pipe Steels from 1000 F Creep and Stress - Rupture Tests.

Similar instances of insensitivity of creep rate to increases in stress in the fine-grain steels were observed in the Bethlehem Steel Co. creep test data on this project, available to the committee

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[6] Metallurgical Engineer, General Electric Co., Schenectady, N. Y.

TABLE XVI.—CREEP RATE DATA FROM STEP-UP CREEP TESTS PERFORMED BY BETHLEHEM STEEL CO.[a]

Heat Designation	Loading	2nd Load Applied, hr	Stress, psi	Creep Rate, per cent per hr	Time, hr
FG1.......	1st		3500	0.000321	1500
	2nd	2300	4500	0.000193	5000
FG2.......	1st		3500	0.000300	1500
	2nd	2500	4500	0.000133	5000
I..........	1st		2500	0.000237	1500
	2nd	2400	5000	0.000375	3000
I..........	1st		2500	0.000230	1500
	2nd	1700	5000	0.000310	3000
I..........	1st		2500	0.000283	1500
	2nd	1700	5000	0.000300	3000
CG1......	1st		3500	0.000065	1500
	2nd	2700	4500	0.000550	6000
CG2......	1st		3500	0.000061	1500
	2nd	2700	4500	0.000517	5500

[a] Metallurgical Report on Cooperative Investigation on the High-Temperature Strength of Carbon Steel—ASTM Specification A 201 Grade B Plate, *Report T-33*, Bethlehem Steel Co., June 26, 1953, furnished to the Joint Committee by J. S. Worth.

through the courtesy of Mr. J. S. Worth. The accompanying Table XVI lists the results of long-time step-up creep tests, in which creep rates were determined after about 1500 hr for the lower of the two stresses, the stress then being raised to the higher value listed and a second rate determined after minimum or steady state creep had been reached.

As can be seen in Table XVI, increasing the stress from 3500 to 4500 psi for fine-grain steels resulted in a lower creep rate, and doubling the 2500-psi stress produced only slight increases in rate. These data for the second loading have also been plotted in Fig. 18. From these observations, it appears that the high creep strengths indicated by the rupture test data are consistent with the data from the lower stressed creep tests and that creep rate is little affected by stress between 0.0001 and 0.0005 per cent per hr.

The data in Table XVI for coarse-grain steels do not show this effect, showing in two cases an eightfold to ninefold increase

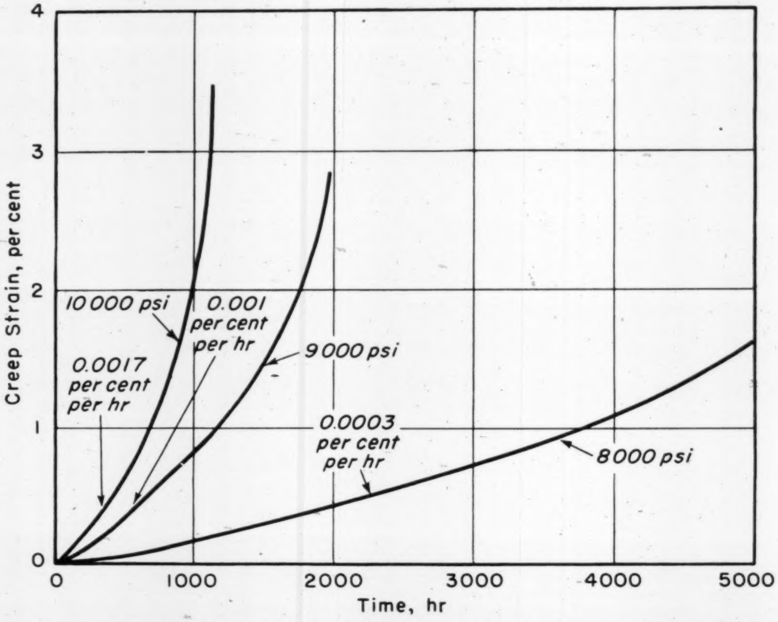

FIG. 19.—Creep Curves from Long Time Stress - Rupture Tests on Plate Steel I.

in rate on increasing the stress from 3500 to 4500 psi.

FIG. 20

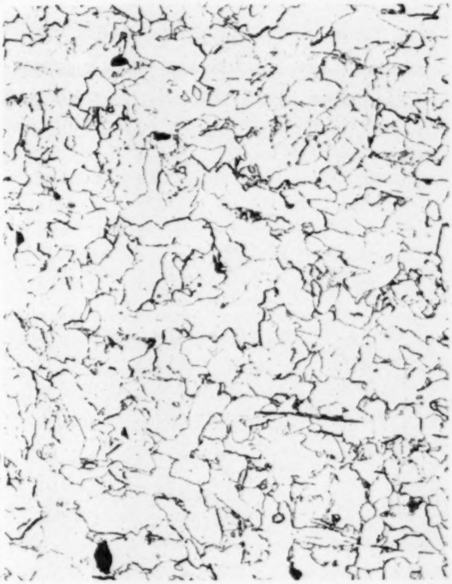

FIG. 21.

FIG. 20.—Microstructure of Threaded Section of Rupture Test Specimen (Plate Steel I) Which Broke After 5637 hr at 8000 psi at 1000 F, as Polished (× 100).

FIG. 21.—Microstructure of Threaded Section of Rupture Test Specimen (Plate Steel I) After 5637 hr at 8000 psi at 1000 F, Nital Etch (× 100).

Some part of the divergence of observed creep behavior between creep and rupture tests may be due to variations in the shape of the creep curve which render creep rate analyses difficult. In the course of analysis of test data obtained on plate steel I by the company with which the writer is associated, only the higher stressed short-time tests were found to have inflections in their creep curves and these were passed in the first few hours of test. The creep curves for the longer time rupture tests (the accompanying Fig. 19) showed that creep rate increased from the time of load application, except for one period of relatively constant creep rate on the 9000-psi test, making impossible a comparison of minimum creep rates. The inflection points at 20,000 and 15,000 psi occurred at about 0.5 per cent plastic strain, and rates computed at that same strain level for the 10,000-, 9000-, and 8000-psi tests produced rates very close to those reported in Table IV.

Metallographic examination of a broken rupture bar after 5637 hr of testing revealed extensive graphitization (the accompanying Fig. 20) and spheroidization (the accompanying Fig. 21) as compared to the initial structure reported for I heat by the author.

In conclusion, it appears from the above that although coarse-grain steels can carry higher loads for creep rates below about 0.0001 per cent per hr, for higher rates, the fine-grain steels appear to be capable of carrying overloads, limited only by the rupture strength, without corresponding increases in creep rate.

MR. R. F. MILLER (*author's closure*).

—The author wishes to thank Mr. Wilder, Messrs. Dickinson, Jackowski, and Freeman, and Mr. Newhouse for the additional information which they have provided on the properties of carbon steel at elevated temperature. These discussions have shed considerable light on the complex creep behavior of these steels. The structural instability of carbon steels at 1000 F, particularly of the steels made to fine-grain practice, may be causing the fluctuation of the creep rate. The final results of the tests at the University of Michigan should clarify this matter further, and are awaited with much interest.

The similarity of long-time rupture strength of the steels made to fine-grain and coarse-grain practice, and the marked disparity in their creep strength, may be explained by the observation that the creep rate of the steels made to fine-grain practice decreases after several thousand hours. Since the ASME tables of allowable working stresses do not distinguish between the two types of steel, it is reassuring to be informed that the creep behavior of the aluminum-deoxidized steel may improve with time.

SIZE EFFECT IN THE TENSION TEST OF MILD STEEL*

By Cedric W. Richards[1]

Synopsis

In 1931 Fujio Nakanishi made his well-known report of a yield point in bending raised by 50 per cent above that in tension, using rectangular beams of mild steel. The presence of a size effect seems to offer the only satisfactory explanation for this and subsequent widely divergent results that have been reported over the past twenty-odd years. The investigation described herein has for its objects the development of an adequate theoretical basis for such a size effect and the testing of its validity by experiment. Due to a similarity between the discontinuous yielding of mild steel and brittle fracture, Weibull's Statistical Theory of the Strength of Materials has been adapted to fit the new problem. Because of its statistical nature, large numbers of tests are required to check the theory. The present report covers the first series of tests, which were made in tension. The experimental results obtained demonstrate a definite dependence of the upper yield point of mild steel on specimen size. Thus the conclusion is reached that in the tension test of mild steel the specimen size is one of the important variables.

The influence of specimen size is a factor that must be considered in an ever widening segment of the field of mechanical testing. The assumption that the results of tests on small laboratory specimens can be used at will in the design of large structural or machine parts is becoming an increasingly risky one. It has been known for some time that brittle fracture is markedly influenced by specimen size. In recent years the case of fatigue has been added to the list. R. E. Peterson (**1**)[2] points out that "large members are weaker in fatigue than tests on small specimens would indicate."

The tension test of ductile metals has always been thought of as a safe example of almost complete absence of size effect. In a closely related test, however—that of pure bending—startling discrepancies have appeared in the case of mild steel. It is a commonly made assumption that a beam of mild steel in pure bending will begin to yield when the maximum stress reaches that at which a tension specimen begins to yield. But in 1931, Nakanishi (**2**) tested beams that were elastic up to 50 per cent above this point, and since that time many investigators have conducted similar experiments with as many different results, ranging all the way down to 0 per cent. These widely varying results have been used to support almost any theory proposed regarding a possible effect of the stress distribution on yielding. The one fact that seems to have been overlooked by all concerned is the very discrepancy between the results of similar bending tests. And the one variable that seems capable of accounting for it is the specimen size, which varied between investigators by a factor of 15 to 1 in the dimensions of the largest and smallest beams used. It now appears evident that this is the factor of primary interest, whereas the presence of the nonuniform stress distribution is of only secondary importance.

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13–18, 1954.

[1] Assistant Professor of Civil Engineering, Stanford University, Stanford, Calif.

[2] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 1000.

A similar situation has been under investigation for many years in the case of brittle fracture. Both in bending and in tension a distinct size effect has been observed and the theoretical aspects have been thoroughly studied by Griffith (**3**), Weibull (**4**), and others. The beginning of yielding in mild steel involves many of the same physical factors that play important parts in brittle fracture. This suggests that similar theories may apply in both cases and that size effect may be of considerable importance in the beginning of yielding.

A study of the behavior of mild steel at the yield point lends credence to this idea, so much so that a program of experimental investigation has been undertaken. The first series of tests consists of tension tests of mild steel specimens of various sizes. The results of these tests demonstrate a definite dependence of the upper yield point on specimen size. Thus the tension test of mild steel takes its place among those tests in which specimen size is an important variable. A second series of tests has been started, involving pure bending of mild steel. Here, too, the evidence points to influence of size effect, but many more tests will be required to establish it.

THE YIELD POINT

The discontinuous yielding of mild steel is a phenomenon that has been the subject of study for many years, and it is still under investigation as engineers attempt to improve their knowledge of this widely used material. The cause of the sudden apparent breakdown of the material at the upper yield point, accompanied by a sharp drop in its load-carrying capacity, is still not completely understood. The first explanation satisfactory to engineers was proposed about 1924. This explanation was that the minute hard particles of cementite which are found assembled along the boundaries of the ferrite grains form a strong skeleton that enables the metal to withstand stresses as high as the upper yield point stress, elastically. At this stress, the explanation continues, the strong skeleton breaks down and the stress drops to the lower yield point, which is determined by the ferrite itself. The concept of the brittle skeleton of cementite has been under attack in recent years. Although it is still widely accepted in the field of applied mechanics, it is only with important modifications.

These modifications are in the form of a generalization from the cementite skeleton to a not completely understood restricting effect of the grain boundaries themselves. It is known that slip is impeded to a varying extent at the grain boundaries of all metals. It has been assumed that this is caused by the distortion of the crystal lattices in the transition region between two crystals. The precipitation of impurities or hard particles along the crystal boundaries has also been suggested as an important factor. The sharp yielding of mild steel is thought to represent an extreme case in which the resistance of the grain boundaries to slip is very high compared to that of the crystals themselves. It is true that the body-centered cubic structure of ferrite is easily deformable, compared to other metallic structures, because of its many slip systems. The resistance of the grain boundaries has been attributed by various investigators to an exceptional hardness of the grain boundaries. For example, A. Eichinger in 1944 suggested that during the formation of the so-called mosaic structure of the ferrite grains certain heterogeneous atoms are precipitated among the ferrite atoms on the surfaces of the mosaic blocks with a hardening effect (**5**). Thus the modified theories simply replace the hard cellular structure of cementite with one of some other form, the basic idea remaining the same.

New Theories:

A number of new theories have been proposed by metallurgists and physicists. These theories are based on research in the atomic structure of mild steel and are thus fundamentally different from the brittle skeleton theory. The mechanism by which slip is at first impeded and then suddenly permitted is thought of in terms of dislocations or migrating interstitial atoms and thus is apparently independent of the grain boundaries. As has been suggested by K. W. Andrews, however, the principal sources of these irregularities are, after all, in the grain boundaries themselves (**6**). Consequently, the difference between the new theories and the brittle skeleton theory is one of degree only. As a result, the generalized brittle skeleton concept can be made to satisfy any of the theories so far proposed; at the same time it conforms closely with observations of the mechanical behavior of mild steel.

Generalized Brittle Skeleton Concept:

On the basis of the brittle skeleton concept, mild steel is thought of as being made up of two components—a strong, brittle component and a soft, easily deformable component. Under an increasing load the soft component is supported in some way by the brittle component, which makes the whole behave elastically up to a certain point. At this point the brittle component fails and the soft component takes over, the materials thereafter behaving in a ductile manner. The beginning of yielding corresponds to the failure of the brittle component, and its similarity to ordinary brittle fracture is at once clear. It therefore appears reasonable that the same factors should govern both.

In the theory developed by Griffith and Weibull for brittle fracture, the cause of failure is envisioned as a flaw of some kind in the material. Specifically, the flaws are referred to as "microcracks" which weaken the material in proportion to their size, although other flaws are included as possibilities. In the case of mild steel there is also good reason to believe that there are flaws distributed at random and that these can be held responsible for the failure of the brittle component. Among such possible flaws are inclusions of foreign matter; small internal cracks or holes formed during some stage of processing or during the growth of the crystals; weak plates of cementite in pearlitic steels; and regions of weakness due to unfavorable orientation of crystals. Most of these flaws are of a nature similar to microscopic cracks, and their effect should be to weaken the material in proportion to their size.

STATISTICAL THEORY

On the basis of the foregoing analysis, a theory governing the beginning of yielding in mild steel can now be developed in the same manner as that governing brittle fracture. If the flaws responsible for the initiation of yielding are distributed at random throughout the material, there will be a corresponding random distribution of strengths of elements of the material. This is the starting point used by Weibull in developing his Statistical Theory of the Strength of Materials (**4**). Applied to the beginning of yielding, this theory leads to the conclusion that the stress at which yielding first takes place decreases with increasing specimen size according to the law:

$$s_u = \frac{s_{u1}}{V^{1/m}} \quad \text{.............} (1)$$

Here s_u is the upper yield point stress for any given specimen, s_{u1} is that for a specimen of unit volume, V is the volume of the given specimen, and m is a material constant (**7**, p. 48).

EXPERIMENTAL INVESTIGATION

In order to test the validity of the statistical law, a large number of tension tests have been carried out on mild steel specimens. The experiments made consisted of three series of conventional tension tests, in which the only significant difference between specimens was size. In series 1, the specimens were $\frac{1}{8}$-in. nominal diameter. In series 4 the nominal diameter was $\frac{1}{2}$ in.—four times that of series 1; and in series 10 it was $1\frac{1}{4}$ in.—ten times that of series 1. The specimens were all made in accordance with ASTM specifications for standard tension test specimens,[3] and geometric similarity of their center portions was preserved throughout. Hence, the volumes were in the ratios of 1:64:1000, for series 1, 4, and 10, respectively.

An incidental result of the statistical theory is that the dispersion to be expected among test results increases with decreasing specimen size. This is expressed by the following equation:

$$\sigma = \frac{a_1}{V^{1/m}} \quad \text{.............} (2)$$

in which σ is the standard deviation, V is the volume of the specimen, a_1 is a material constant, and m has the same value as in Eq 1. Therefore, if comparable accuracy were to be obtained from the three series, it was considered desirable to include larger numbers of tests in the smaller sizes.

In tests for the upper yield point, a number of factors that can ordinarily be neglected in other types of tests assume great importance. Factors such as axiality of loading, shape of fillets, and rate of strain must be carefully controlled in order to study the effect of any single variable. In these experiments it was necessary that size be the only important variable. To accomplish this, great care and special precautions were required (**7**, pp. 50–64). The material itself was given particularly careful treatment. All specimens were annealed after machining and polishing in order to remove all effects that might tend to disturb the yield point and to make all specimens uniform in quality. The annealing was done in a furnace having a controlled atmosphere (containing 35 per cent H_2 and 20 per cent CO) so that the surfaces of the specimens would be unaffected. Examination of the microstructure after annealing showed that grain sizes were substantially the same in various sizes of specimens and that no significant carburization had taken place in the surface of the steel. It should also be noted that all specimens were machined from the same bar of C1020 steel.

Results:

The tests themselves were of the simplest kind. Using a high-capacity hydraulic testing machine, the specimens were loaded at a uniform rate until the load-indicating hand suddenly dropped back. The upper yield point load thus obtained was recorded, and the test was over. Table I gives the average data from each series of tests, including the number and dimensions of specimens and the upper yield point stresses.

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[3] Tentative Methods of Tension Testing of Metallic Materials (E 8 – 52 T), 1952 Book of ASTM Standards, Part 1, p. 1389.

TABLE I.—SUMMARY OF RESULTS OF TENSION TESTS.

	Number of Specimens Included	Diameter		Length of Reduced Section, in.	Volume, units[a]	s_u, psi
		Nominal, in.	Average Actual, in.			
Series 1	18	$\frac{1}{8}$	0.1255	$\frac{1}{2}$	1	60 300
Series 4	13	$\frac{1}{2}$	0.503	2	64	55 600
Series 10	10	$1\frac{1}{4}$	1.260	5	1000	53 550

[a] One volume unit = volume in series 1.

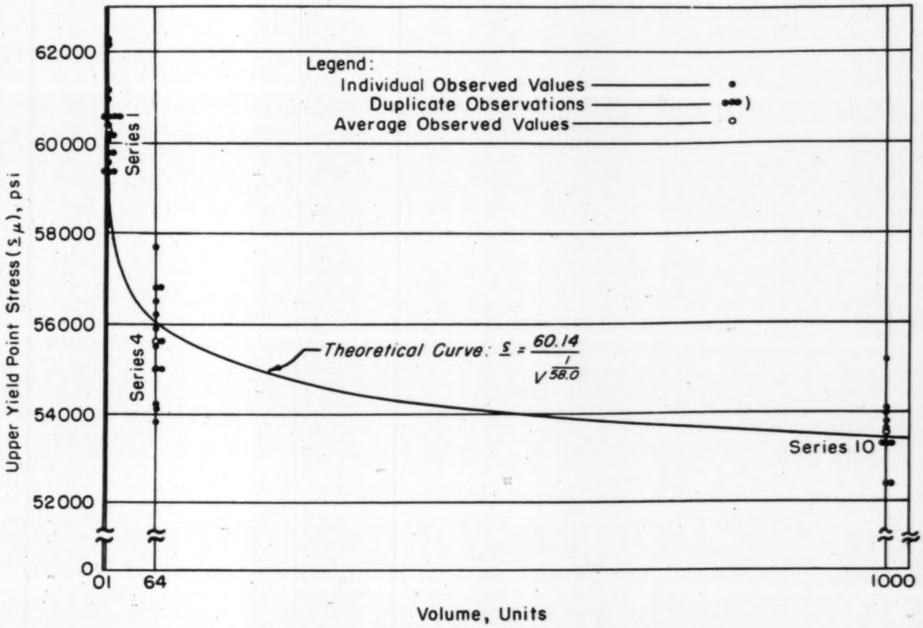

FIG. 1.—Variation of Upper Yield Point Stress with Volume.

In Fig. 1 the average values of s_u are plotted against the volumes of the specimens. In addition, all of the values observed for the individual specimens are plotted in order to show their distribution. Using the three points representing the average observed values, a comparison may now be made between experimental results and the statistical theory. Equation 1, representing the theory, requires only two points to determine its two constants. Consequently, the validity of the theory will be indicated by the degree of accuracy with which it can be made to fit all three points. Using the method of least squares, Eq 1 becomes (**7**, pp. 69–72):

$$s_u = \frac{60.14}{V^{1/58.0}} \qquad (3)$$

and the resulting curve is shown in Fig. 1. A comparison between the values obtained from this theoretical curve and the observed values shows percentage differences of 0.33, 0.72, and 0.28 for series 1, 4, and 10, respectively. These differences are well within experimental error.

CONCLUSIONS

The experimental investigation provides positive quantitative evidence of a size effect on the upper yield point of mild steel in tension. This size effect is graphically illustrated in Fig. 1. A theoretical variation developed on the basis of statistical theory shows a very good correlation with the observed data. This gives support to a statistical theory for the initiation of discontinuous yielding.

In order to establish the statistical theory, much further research will be required. Tests of mild steel in pure bending are under way, and the first results appear to support the theory (**7**, Chapter III.) Other types of loading should also be investigated, since the statistical theory predicts an effect of this variable also.

Acknowledgment:

The author is grateful for the inspiration and encouragement given him during this investigation by Donovan H. Young and S. P. Timoshenko. He also takes this opportunity to express appreciation to Stanford University for financial aid in defraying the cost of specimens and machining connected with the experimental phases of this work, and to the Dexter Metal Treating Co. of Oakland, Calif., which gave its services in the heat treating of specimens.

REFERENCES

(**1**) R. E. Peterson, "Review of the Fatigue of Materials Field," *Applied Mechanics Reviews*, Vol. 5, No. 1, January, 1952, pp. 1–3.

(**2**) F. Nakanishi, "On the Yield Point of Mild Steel," *Report of the Aeronautical Research Institute, Tokyo Imperial University*, Vol. 6, pp. 83–140 (1931).

(**3**) A. A. Griffith, "The Phenomena of Rupture and Flow in Solids," *Philosophical Transactions*, Royal Soc. (London), Series A, Vol. 221, pp. 163–198 (1920).

(**4**) W. Weibull, "A Statistical Theory of the Strength of Materials," *Ingeniörs Vetenskaps Akademien, Handlingar*, Nr. 151, 45 pp. (1939).

(**5**) A. Nadai, "Theory of Flow and Fracture of Solids," McGraw-Hill Book Co., Inc., New York, N. Y., Vol. I, p. 286 (1950).

(**6**) A. H. Cottrell, "Effect of Solute Atoms on the Behavior of Dislocations," The Physical Society, London, p. 36 (1948). Report of a Conference on Strength of Solids, University of Bristol, July, 1947.

(**7**) C. W. Richards, "The Effect of Specimen Size on the Beginning of Yielding in Mild Steel," Ph.D. Dissertation, Stanford University, Stanford, Calif., March, 1953.

DISCUSSION

MR. WILL J. WORLEY[1] (*by letter*).—The author has presented analysis of test data with three different volume ratios. Equation 1 of the paper may be plotted as a straight line on log-log paper and will have a slope of −1. If the data presented for the three volume ratios 1, 64, and 1000 are also plotted on the same log-log paper, the same height of vertical scatter band at any given volume ratio will represent the same per cent deviation from the mean position represented by Eq 1. Thus, the dispersion theory can be checked by noting the elevation or height of the scatter band when the data are plotted on log-log paper.

A variable which the author has not discussed is the ratio of the size of the rolled bar from which the specimens were cut to the size of the specimen. Since all of the specimens were cut from the same bar of C1020 steel, the ratio of the diameter of the test section to the diameter of the rolled bar is much smaller for the small diameter specimens. While this effect is more pronounced for rimmed steel where the chemical composition of the steel near the surface is different from that near the center of the bar, it may also be important for killed steel. The author's comments on these points would be of value.

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[1] Assistant Professor of Theoretical and Applied Mechanics, College of Engineering, University of Illinois, Urbana, Ill.

MR. FRANK A. MCCLINTOCK[2] (*by letter*).—A further check on the applicability of Weibull's theory may be made by noting that the material constants s_{u1} in Eq 1 and a_1 in Eq 2 of the paper are related to each other through the constant m. For the general case in which the lowest stress at which any specimen will first yield is s_0, and writing I_m of Weibull's theory in terms of the gamma function, $I_m = \Gamma\,(1 + 1/m)$, one finds

$$s_u = (s/V^{1/m})\Gamma(1 + 1/m) + s_0 \ldots\ldots (1)$$

$$\sigma = (s/V^{1/m})\Gamma(1 + 1/m) \cdot \sqrt{\frac{\Gamma(1 + 1/m)}{\Gamma^2(1 + 1/m)} - 1} \ldots (2)$$

Hence,

$$\sigma = (s_u - s_0) \sqrt{\frac{\Gamma(1 + 2/m)}{\Gamma^2(1 + 1/m)} - 1} \ldots (3)$$

It is also of interest to see what size effect would be expected from the asymptotic extreme-value distribution with the cumulative distribution[3]

$$P = 1 - \exp\{-\exp[\alpha(s - s_1) + \ln V]\} \ldots (4)$$

This arises if there is no lower limit below which the specimen will not yield. The mean life is given by

$$s_u = s_1 - \frac{(\gamma + \ln V)}{\alpha} \ldots\ldots\ldots (5)$$

where $\gamma = 0.57722$ and the standard deviation by

$$\sigma = \frac{\pi}{\alpha\sqrt{6}} \ldots\ldots\ldots\ldots (6)$$

Confidence limits of 95 per cent for the mean and standard deviation of the upper yield point are given in the accompanying Table II. Although the confidence limits are those for a normally distributed variable, which is not the case here, the limits should still give an approximate idea of the uncertainty in our knowledge of these quantities. Table II also includes theoretical values. The first case is that given by the author, the second has parameters chosen to give an exact fit to the data on size effect, and the third is the best fit for the extreme-value distribution of Eqs 4 to 6. In all cases the mean values are within the experimentally determined confidence intervals and the standard deviations agree except for the first two cases in regard to the smallest specimens. Even in these cases the disagreement is not serious.

Such a good fit would not be obtained for both the mean values and the standard deviations if the surface area, rather than the volume, were taken as the important index of size. In that case, if the data on mean life were fitted, m and α would become $\frac{2}{3}$ of their former values, and the theories would then predict standard deviations $1\frac{1}{2}$ times their former values. Put the other way around, it would mean that some of the size effect was due to factors other than the statistics of the problem. In any event, it does not appear possible to decide between the logarithmic and power laws for size effect on the basis of these data.

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[2] Assistant Professor of Mechanical Engineering, Massachusetts Institute of Technology, Cambridge, Mass.

[3] See for example, the paper by E. J. Gumbel, "Statistical Theory of Extreme Values and Some Practical Applications," U. S. Dept. of Commerce Nat. Bureau of Standards, *Applied Mathematics Series No. 33* (1954).

TABLE II.—CONFIDENCE LIMITS OF 95 PER CENT FOR THE MEAN AND STANDARD DEVIATION OF THE UPPER YIELD POINT.

	Series 1	Series 4	Series 10
Data:			
s_u, psi	60 300 ± 400	55 600 ± 700	53 550 ± 600 (95 per cent)
σ, psi	600–1300	800–2000	600–1600 (95 per cent)
Theory: $s_0 = 0$; $s_{u1} = 60\,140$ psi; $m = 58.0$			
s, psi	60 140	56 000	53 400
σ, psi	1 320	1 230	1 180
Theory: $s_0 = 47\,000$ psi; $m = 10.0$			
s, psi	60 300	55 600	53 550
σ, psi	1 600	1 040	790
First extreme-value distribution: $\alpha = 0.001023$ in^2 per lb			
s, psi	60 100	56 050	53 350
σ, psi	1 250	1 250	1 250

In these tests was the strain rate, as opposed to the loading rate, held constant for all sizes? If not, what effect might variations in strain rate have had on the upper yield points for the ranges of strain rate encountered?

MR. C. W. RICHARDS (*author's closure*).—With reference to Mr. Worley's question concerning the effect of the ratio of original bar size to specimen size, it was assumed at the time the tests were made that this would not be an important factor. The steel used was not rimmed steel and an examination of the microstructure showed substantial uniformity across the diameter of the original bar, which was $1\frac{1}{2}$ in. Further tests are now under way, including a more detailed investigation of this effect. It is expected that these tests will provide sufficient evidence to answer such questions as those raised by Mr. McClintock in his interesting discussion. His last question may be answered by pointing out that each of the tension tests was carried out entirely in the elastic range, being terminated at the upper yield point. Consequently, a constant strain rate was maintained simply by maintaining a constant loading rate.

EFFECT OF MICROSTRUCTURE ON THE ELEVATED-TEMPERATURE STRENGTH OF ALLOY STEEL*

By J. J. Heger,[1] J. M. Hodge,[1] and P. W. Marshall[1]

Synopsis

The tensile properties at room temperature and at 1000, 1100, and 1200 F, the ductility-transition temperature, and the creep-rupture strengths at 1000, 1100, and 1200 F in a 2 per cent chromium, ½ per cent molybdenum steel were evaluated as a function of microstructure. The microstructures studied were as follows:

1. Coarse pearlite and ferrite.
2. Fine pearlite and ferrite.
3. Upper bainite.
4. Lower bainite.
5. Martensite.

The elevated-temperature strengths of the various microstructures differed significantly for short testing times, but these differences decreased markedly as the time and temperature of testing increased.

In the past few years, there has been an increasing demand for alloy steels with good mechanical properties at elevated temperatures, and the minimum service temperature at which good mechanical properties are desired continues to be raised as the operating temperatures of elevated-temperature equipment are raised. Therefore, the U. S. Steel Corp. is conducting a long-range research program to provide fundamental information for the development of an alloy steel that contains a minimum amount of alloy and that after heat treatment exhibits elevated-temperature properties superior to those of present alloy steels.

The first phase of this program is concerned with the effect of microstructure on the elevated-temperature (1000 to 1200 F) properties of alloy steel. The second phase will be concerned with the specific effects of carbide-forming alloying elements on the elevated-temperature properties of alloy steel heat-treated to a specific microstructure. The present report describes the results of the first phase of the program.

At the time the present investigation was begun, German investigators (**1, 2**)[2] had made some studies relating to the effect of microstructure on elevated-temperature properties. Although most of the German work was limited to short-time tests at 932 F (500 C), some short-time tests were conducted at temperatures from 750 F (400 C) to 1112 F (600 C). The results of the latter tests indicate that at the lower temperatures a steel with a bainite microstructure is stronger than one with either a pearlite or a martensite microstructure and that, in general, the strengths associated with all three microstructures are more nearly the same as the test temperature is increased to 1112 F.

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13–18, 1954.

[1] United States Steel Corp., Pittsburgh, Pa.

[2] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 1027.

MATERIALS AND EXPERIMENTAL WORK

Two 100-lb induction-furnace ingots, the compositions of which are shown in Table I, were cast and were forged to $\frac{5}{8}$-in. square bars. Since the principal differences in the compositions of the bars of the two ingots are small—0.02 per cent carbon, 0.09 per cent chromium, and 0.01 per cent molybdenum—the bars from both ingots were considered to be samples of the same steel.

The alloy content of the steel was chosen on the basis (1) of providing sufficient hardenability so that the steel might be heat-treated to several microstructures—coarse and fine pearlite plus ferrite, upper and lower bainite, and martensite; and (2) of providing sufficient oxidation resistance so that creep-rupture tests at temperatures as high as 1200 F might not be complicated by oxidation of the test specimens. Therefore, an alloy content of about 0.50 per cent manganese, about 2.00 per cent chromium, and about 0.50 per cent molybdenum was selected; in addition, the steel was deoxidized with silicon only.

To produce a uniform initial microstructure in the steel before heat treatment, all the bars were normalized after being austenitized for 1 hr at 1700 F. The 1700 F temperature was selected as both the normalizing temperature and the austenitizing temperature for subsequent heat treatments because hardness measurements and microscopic examination of specimens water-quenched from several temperatures in the range 1700 to 2100 F indicated that essentially complete solution of the carbides in this steel occurs in 1 hr at 1700 F.

The hardenability of the steel was determined with insert-type end-quench hardenability specimens.[3] One specimen was obtained from a bar of each ingot. The hardenability specimens were end-quenched after being austenitized for 1 hr at 1700 F, and then hardness measurements were made on the specimens in the usual way.

To determine the heat treatments required to produce the desired pearlitic and bainitic microstructures in the 2 per cent chromium, $\frac{1}{2}$ per cent molybdenum steel, the isothermal transformation characteristics of the steel were determined. Thin sections were cut from the bars, austenitized for 1 hr at 1700 F, transferred to lead or salt baths, and then held for various times at each of several temperatures in the range 650 to 1250 F.

TABLE I.—COMPOSITION OF STEELS, PER CENT.
Check Analyses.

Ingot	Carbon	Manganese	Phosphorus	Sulfur	Silicon	Chromium	Molybdenum	Aluminum (Acid-Soluble)	Nitrogen
No. B657	0.27	0.56	0.011	0.025	0.16	1.99	0.49	0.004	0.007
No. B658	0.25	0.56	0.012	0.025	0.16	2.08	0.50	0.006	0.007

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[3] Tentative Method of End-Quench Test for Hardenability of Steel (A 255 – 48 T), Appendix, 1952 Book of ASTM Standards, Part 1, p. 566

The specimens were water-quenched and then examined microscopically. From the data obtained, an isothermal transformation diagram was constructed.

TABLE II.—HEAT TREATMENTS USED TO PRODUCE DESIRED MICROSTRUCTURES IN A 2 PER CENT CHROMIUM, ½ PER CENT MOLYBDENUM STEEL.

Microstructure	Austenitizing Conditions			Isothermal Transformation			Tempering Conditions[a]		
	Temperature, deg Fahr	Time, hr	Quenchant	Temperature, deg Fahr	Time hr	Quenchant	Temperature, deg Fahr	Time, hr	Quenchant
Coarse pearlite	1700	1	...	1350	5	Water	1100	2	Water
Fine pearlite	1700	1	...	1200	72	Water	1100	2	Water
Upper bainite	1700	1	...	850	200	Water	1100	2	Water
Lower bainite	1700	1	...	650	½	Water	1100	2	Water
Martensite	1700	1	Water	...	...	...	1100	1	Water
Martensite	1700	1	Water	...	...	...	1200	1	Water

[a] In addition to the tempering conditions listed, because of the testing procedures employed, all the creep-rupture specimens were tempered for 14 to 15 hr at the testing temperature prior to application of the load, and all the elevated-temperature tensile specimens were tempered for about ½ hr at the testing temperature prior to application of the load.

NOTE.—In all instances ⅝-in. square bars were heat treated.

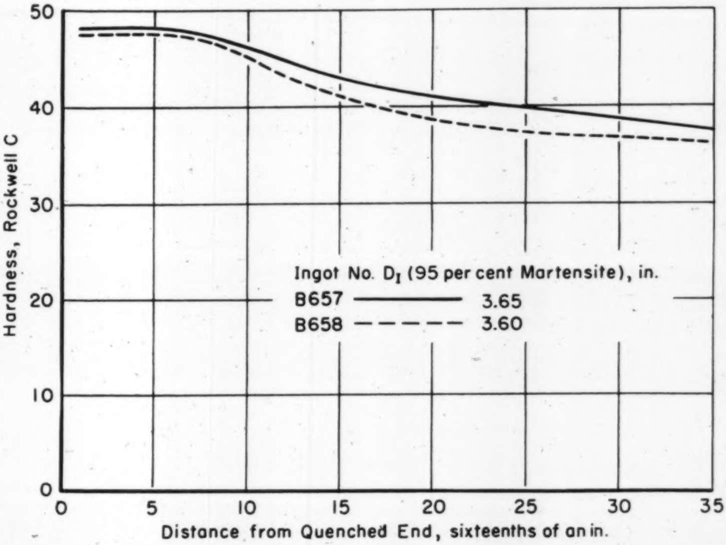

FIG. 1.—End-Quench Hardenability Curves for Two Ingots of a 2 per cent Chromium, ½ per cent Molybdenum Steel.

The Ae_1 and Ae_3 critical temperatures were estimated to be 1425 and 1495 F, respectively. In addition, the martensite temperature (M_s) was calculated from the equation of Stewart and Grange (3).

The heat treatments to obtain the pearlitic and bainitic microstructures were then selected from the isothermal transformation data. A microstructure of martensite was obtained by water-quenching the bars. It was recognized that in creep-rupture tests at 1200 F the effect of tempering at a lower temperature is negligible. To standardize on a single tempering temperature at which the carbides would not be excessively spheroidized, test bars transformed to each of the desired microstructures were tempered at 1100 F. In addition, test bars transformed to martensite were tempered at 1200 F to determine the effect of the higher tempering temperature on the mechanical properties of this microstructure. Table II gives a complete record of the heat treatments used in the present work.

The following test specimens were machined from the bars heat treated to each of the different microstructures: 0.252-in. diameter tension specimens, keyhole-notched Charpy impact specimens, 0.254-in. diameter elevated-temperature tension specimens, and 0.252-in. diameter creep-rupture specimens.

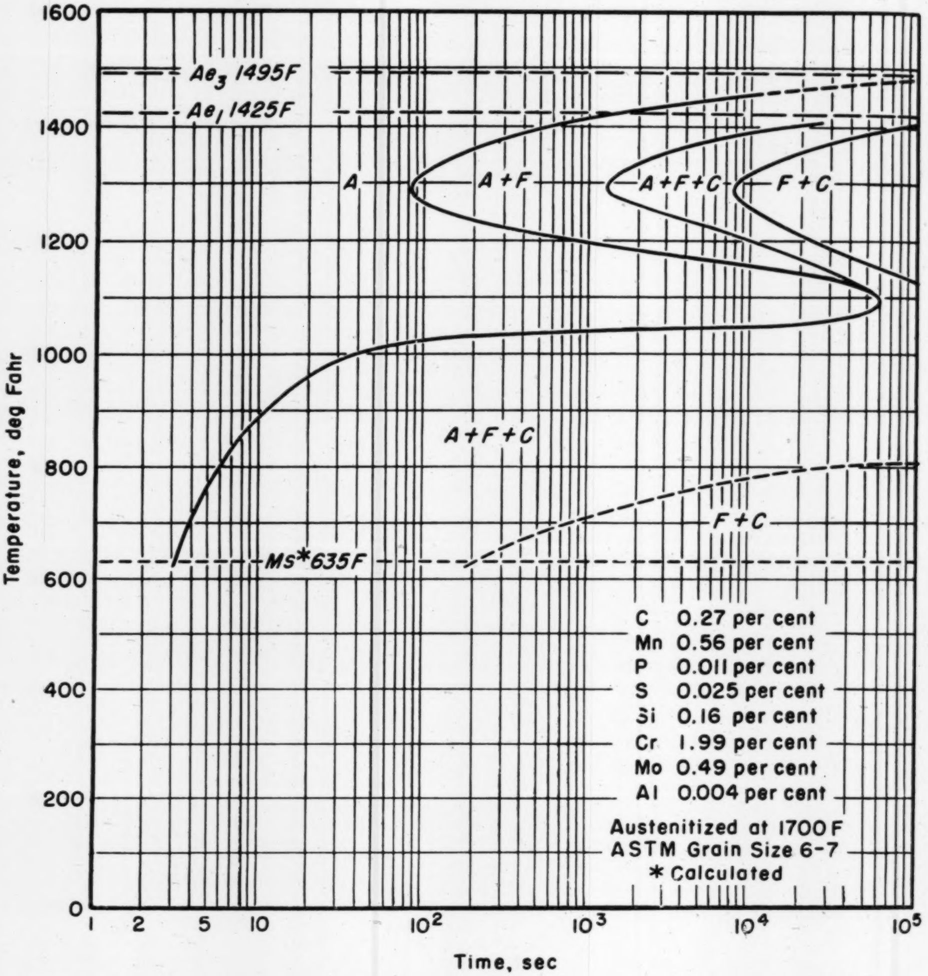

FIG. 2.—Isothermal Transformation Diagram for a 2 per cent Chromium, ½ per cent Molybdenum Steel.

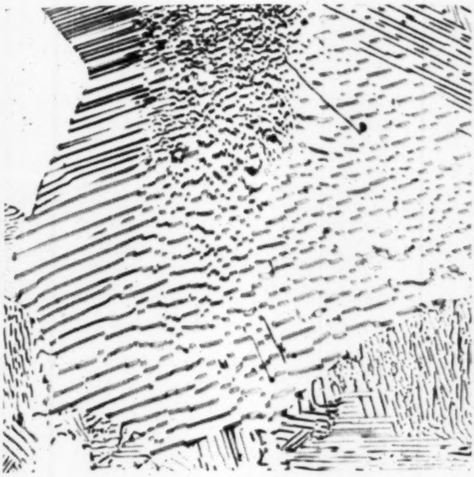

FIG. 3.—Coarse Pearlite Formed in a 2 per cent Chromium, $\frac{1}{2}$ per cent Molybdenum Steel During 5 hr at 1350 F, Super Picral Etch (× 1000).

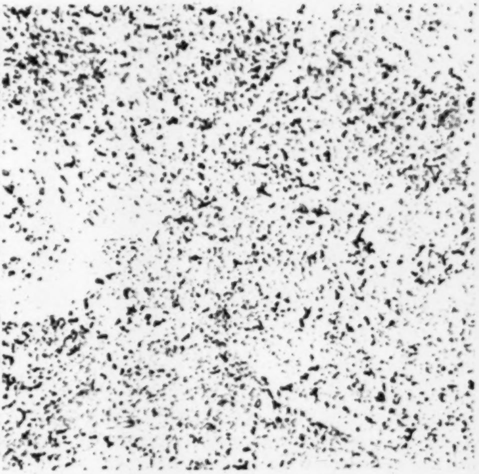

FIG. 4.—Fine Pearlite (Spheroidized) Formed in a 2 per cent Chromium, $\frac{1}{2}$ per cent Molybdenum Steel During 72 hr at 1200 F, Super Picral Etch (× 1000).

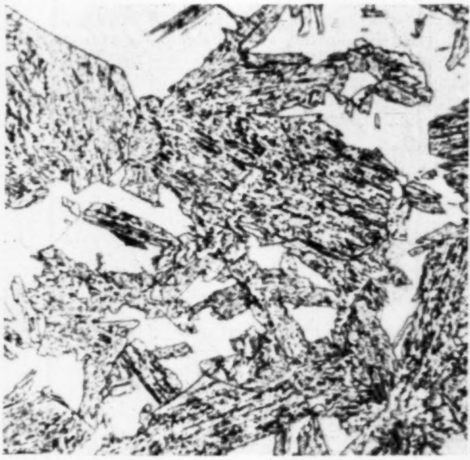

FIG. 5.—Upper Bainite Formed in a 2 per cent Chromium, $\frac{1}{2}$ per cent Molybdenum Steel During 50 sec at 850 F, Super Picral Etch (× 1000).

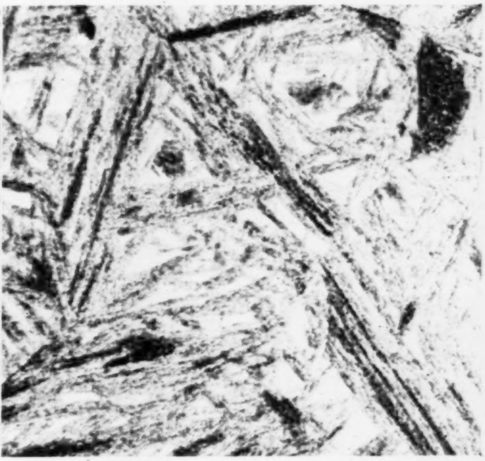

FIG. 6.—Lower Bainite Formed in a 2 per cent Chromium, $\frac{1}{2}$ per cent Molybdenum Steel During 30 sec at 650 F, Super Picral Etch (× 1000).

Tension tests were made at room temperature, 1000, 1100, and 1200 F; creep-rupture tests were made at 1000, 1100, and 1200 F; and impact tests were made at several temperatures from +200 to −280 F so that ductility transition temperatures might be determined.

RESULTS AND DISCUSSION

Hardenability and Transformation Characteristics:

The results of the end-quench hardenability tests, Fig. 1, show that the hardenability of the steel from the two ingots is the same. The small difference in the hardness level of the two curves is probably due to the difference in carbon content.

TABLE III.—TENSILE AND IMPACT PROPERTIES OF A 2 PER CENT CHROMIUM, ½ PER CENT MOLYBDENUM STEEL HEAT TREATED TO SEVERAL MICROSTRUCTURES.

Microstructure	Yield Strength, psi	Tensile Strength, psi	Elongation in 1 in., per cent	Reduction of Area, per cent	Ductility-Transition Temperature, deg Fahr
Coarse pearlite[a]	46 900	68 700	34.0	68.7	+28 ±17
Fine pearlite[a]	57 500	92 500	27.0	71.6	−30 ±25
Upper bainite[a]	136 300	160 700	15.5	67.0	+50 ±30
Lower bainite[a]	115 900	135 600	17.0	68.5	−185 ±25
Martensite[a]	130 700	148 800	18.0	65.2	−225 ±25
Martensite[b]	96 200	110 200	22.5	74.8	−200 ±15

[a] Tempered at 1100 F.

[b] Tempered at 1200 F.

NOTES.—Duplicate 0.252-in. diameter tensile specimens were tested.

Keyhole-notched Charpy impact specimens were tested, and the ductility-transition temperature was determined at the middle of the scatter band at an energy of 10 to 15 ft-lb.

For the present steel, the Ae_1 temperature is 1425 F, the Ae_3 temperature is 1495 F, and the calculated M_s temperature is 635 F. These data are shown on the isothermal transformation diagram, Fig. 2.

In the temperature range of pearlite formation, isothermal transformation begins in the shortest time (1½ min) at 1300 F and is complete in the shortest time (2 hr) at the same temperature. At temperatures between 1495 (Ae_3) and 1100 F, proeutectoid ferrite is the first constituent to form, whereas at temperatures between 1100 F and 635 F (M_s), bainite is the first product to form. Transformation to bainite begins in the shortest time (about 3 sec) just above the M_s temperature and is 99 per cent complete in the shortest time (3 min) at the same temperature.

The isothermal transformation diagram in Fig. 2 is similar to one reported by Manning and Lorig (4) for a 0.30 per cent carbon, 2.04 per cent chromium, 0.33 per cent molybdenum steel. As might be expected, the diagram for the latter steel (0.33 per cent molybdenum) indicates a more rapid transformation in the pearlite range than does the diagram for the present steel (0.50 per cent molybdenum). An isothermal transformation diagram for a chromium-molybdenum steel (0.31 per cent carbon, 2.08 per cent chromium, 0.48 per cent molybdenum) was also reported by Delbart and Potaszkin (5); in general, the shape of their diagram is similar to that of the present one, but the temperature of most rapid transformation to pearlite is somewhat higher and the temperature of most rapid transformation to bainite is somewhat lower than that shown in Fig. 2.

In the present steel the pearlite formed at 1350 F was considered to be representative of coarse pearlite, and that formed at 1200 F was considered to be representative of fine pearlite. These microstructures are illustrated in Figs. 3 and 4. The bainite formed at 850 F was considered to be representative of upper bainite, and that formed at 650 F was considered to be representative of lower bainite. The time required for complete transformation at 850 F is quite long; it was necessary to hold the test specimens for 200 hr at this temperature, despite the fact that about 99 per cent of the austenite had transformed in about 72 hr. The bainitic microstructures are illustrated in Figs. 5 and 6, which show partial transformation at 850 and at 650 F.

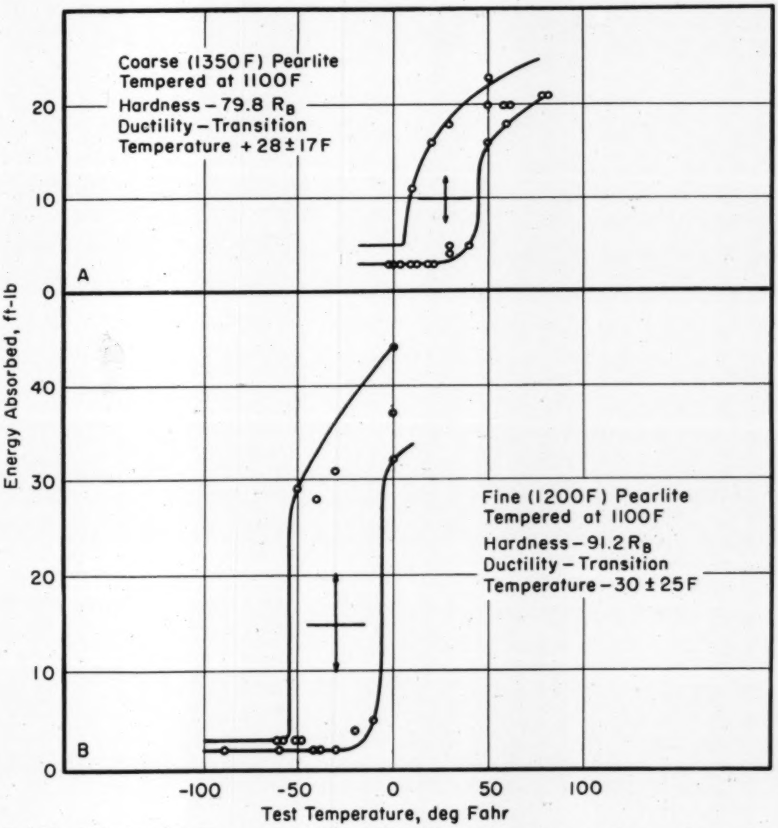

FIG. 7.—Keyhole-Notch Charpy Ductility-Transition Temperature Curves for a 2 per cent Chromium, ½ per cent Molybdenum Steel Heat-Treated to Coarse and to Fine Pearlite.

(*a*) Coarse (1350 F) pearlite tempered at 1100 F. Hardness—79.8 R_B; ductility-transition temperature—+28 ±17 F.

(*b*) Fine (1200 F) pearlite tempered at 1100 F. Hardness—91.2 R_B; ductility-transition temperature— −30 ±25 F.

Room-Temperature Tensile and Low-Temperature Impact Properties:

The results of the room-temperature tension tests are summarized in Table III. Of all the microstructures, the coarse pearlite[4] has the lowest tensile and yield

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[4] When reference is made to the mechanical properties of a microstructural constituent, the properties of the steel heat-treated to the particular microstructure are implied.

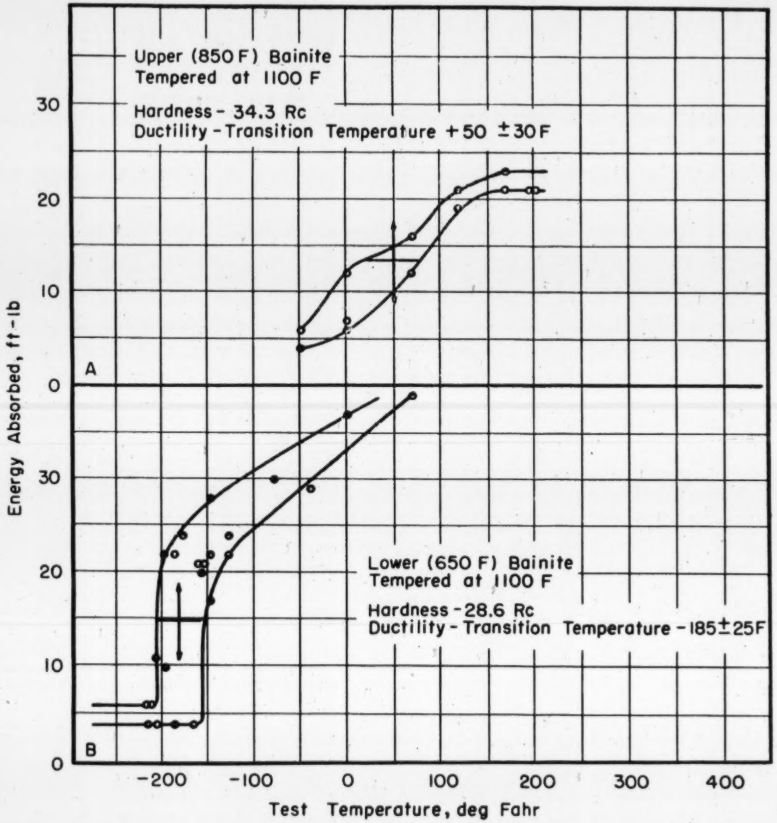

FIG. 8.—Keyhole-Notch Charpy Ductility-Transition Temperature Curves for a 2 per cent Chromium, ½ per cent Molybdenum Steel Heat-Treated to Upper and to Lower Bainite.

(*a*) Upper (850 F) bainite tempered at 1100 F. Hardness—34.3 R_C; ductility-transition temperature— +50 ±30 F.

(*b*) Lower (650 F) bainite tempered at 1100 F. Hardness—28.6 R_C; ductility-transition temperature— −185 ±25 F.

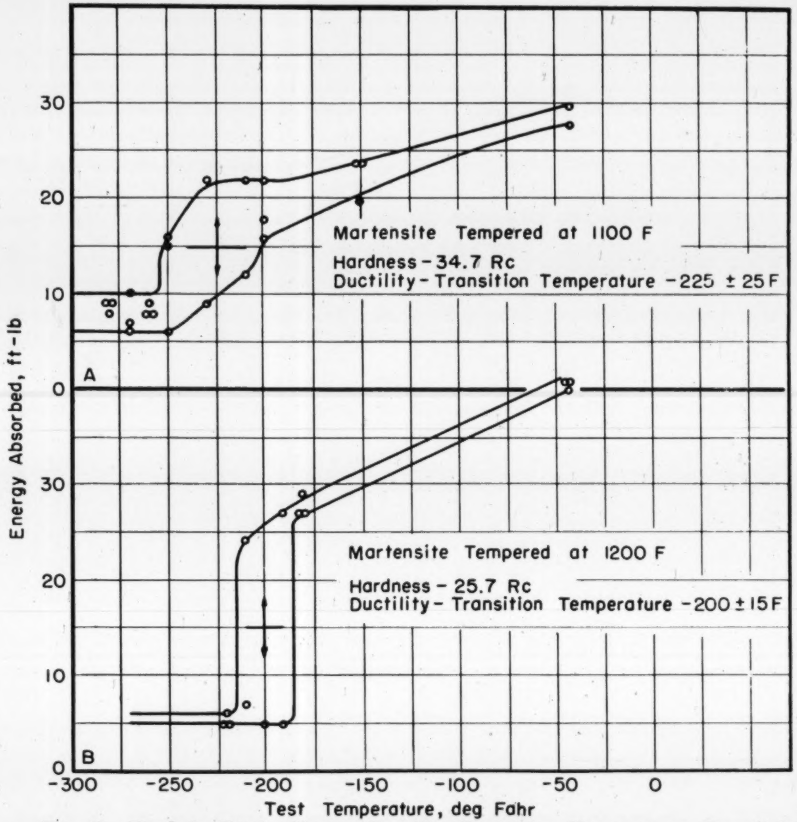

FIG. 9.—Keyhole-Notch Charpy Ductility-Transition Temperature Curves for a 2 per cent Chromium, ½ per cent Molybdenum Steel Heat-Treated to Martensite.

(*a*) Martensite tempered at 1100 F. Hardness—34.7 R_C; ductility-transition temperature— −225 ±25 F.

(*b*) Martensite tempered at 1200 F. Hardness—25.7 R_C; ductility-transition temperature— −200 ±15 F.

strengths and the fine pearlite has the next lowest; the elongation of both the coarse and the fine pearlite is higher than that of the other microstructures.

Of the acicular transformation products (bainite or martensite) tempered at 1100 F, the upper bainite has the highest tensile and yield strengths. This indicates that the upper bainite, which was weaker than the martensite or the lower bainite before being tempered, resisted softening at 1100 F better than did the martensite or the lower bainite. The strengths of the lower bainite tempered at 1100 F, on the other hand, are lower than those of either the martensite or the upper bainite tempered at 1100 F. This presumably reflects the lower, as-transformed hardness of the lower bainite together with a tempering rate similar to that of martensite.

TABLE IV.—TENSILE PROPERTIES AT 1000, 1100, AND 1200 F OF A 2 PER CENT CHROMIUM, ½ PER CENT MOLYBDENUM STEEL HEAT TREATED TO SEVERAL MICROSTRUCTURES.

Microstructure	Temperature, deg Fahr	Yield Strength, 0.2 per cent offset, psi	Tensile Strength, psi	Elongation in 1 in., per cent	Reduction of Area, per cent
Coarse pearlite[a]	1000	25 200	56 400	39.0	80.5
	1100	20 800	42 000	56.5	90.0
	1200	17 400	31 500	65.5	91.0
Fine pearlite[a]	1000	39 400	54 400	45.0	86.5
	1100	33 800	42 000	50.0	89.0
	1200	25 800	34 700	52.0	91.0
Upper bainite[a]	1000	...	96 000	20.0	71.5
	1100	59 700	80 000	33.0	82.0
	1200	30 300	47 200	42.5	90.0
Lower bainite[a]	1000	79 400	96 500	24.0	73.0
	1100	64 500	73 000	30.0	82.0
	1200	29 600	48 700	45.0	85.5
Martensite[a]	1000	90 000	101 000	20.0	73.0
	1100	57 500	76 700	33.0	83.5
	1200	26 500	44 900	41.0	90.5
Martensite[b]	1000	74 500	90 200	24.0	76.0
	1100	48 800	67 200	30.0	84.5
	1200	22 400	49 200	52.5	91.5

[a] Tempered at 1100 F.
[b] Tempered at 1200 F.

Notes.—Duplicate, special 5-in. long, 0.254-in. diameter tensile specimens were tested.

In equalizing the elevated-temperature tensile specimens at the testing temperature, all the specimens were tempered for about ½ hr at the testing temperature.

The ductility values for all of the acicular structures tempered at 1100 F are about the same.

As might be expected, the strength of the martensite tempered at 1200 F is lower and the ductility is higher than the corresponding properties of the other acicular transformation products tempered at 1100 F.

The ductility-transition temperatures are also shown in Table III, and the complete energy-temperature curves from which the transition temperatures were determined are shown in Figs. 7 to 9.

Of the microstructures tempered at 1100 F, the martensite has the lowest ductility-transition temperature, and the lower bainite has the next lowest. The long-time treatment at 850 F is probably a factor in the relatively higher transition temperature of the upper bainite, 50 F (Table II). The transition temperatures of the pearlites are much higher than those of the martensite and the lower bainite; and the transition temperature of the fine pearlite, −30 F, is appreciably lower than that of the coarse pearlite, +28 F. Although the tensile strength of the martensite tempered at 1200 F is about 38,000 psi lower than that of the martensite tempered at 11 F, the transition temperature of the martensite tempered at 1200 F is higher than the transition temperature of the martensite tempered at 1100 F, rather than lower.

Elevated-Temperature Tension Tests:

The results of the elevated-temperature tension tests at 1000, 1100, and 1200 F are given in Table IV. In general, the yield and tensile strengths of the acicular transformation products are higher than those of either the coarse or the fine pearlite. When the test temperature is increased, the difference between the strength of the acicular products and that of the pearlite decreases. For example, at 1000 F the tensile strength of the coarse pearlite is about 56 per cent that of the martensite tempered at 1100 F, but at 1200 F the tensile strength of the coarse pearlite is about 72 per cent that of the martensite tempered at 1200 F.

TABLE V.—CREEP AND CREEP-RUPTURE DATA FOR A 2 PER CENT CHROMIUM, ½ PER CENT MOLYBDENUM STEEL HEAT-TREATED TO SEVERAL MICROSTRUCTURES.

Microstructure	Temperature, deg Fahr	Stress for Rupture, psi			Stress for a Minimum Creep Rate of 0.001 per cent per hr, psi
		100 hr	1000 hr	10,000 hr	
Coarse pearlite[a]	1000	35 800	26 500	19 000	19 000
	1100	19 300	12 900	8 400	8 500
	1200	11 800	7 200	4 400	3 800
Fine pearlite[a]	1000	31 000	26 500	22 500	23 000
	1100	21 000	13 900	8 800	9 200
	1200	11 800	6 200	3 000	4 600
Upper bainite[a]	1000	63 000	38 500	24 300	22 000
	1100	27 000	16 500	10 000	11 500
	1200	12 300	7 100	4 100	3 600
Lower bainite[a]	1000	55 000	35 500	24 200	21 000
	1100	26 800	16 500	10 000	10 500
	1200	12 100	6 700	3 700	3 400
Martensite[a]	1000	52 500	36 000	24 000	29 000
	1100	25 300	15 500	9 400	9 600
	1200	10 700	6 000	3 400	3 600
Martensite[b]	1000	45 000	33 000	24 000	24 500
	1100	24 200	14 500	9 000	8 300
	1200	11 000	6 000	3 600	3 000

[a] Tempered at 1100 F.

[b] Tempered at 1200 F.

NOTES.—Standard 0.252-in. diameter creep-rupture specimens were tested. The 10,000-hr creep rupture strengths and the minimum creep-rate stresses are extrapolated values.

In equalizing the creep-rupture specimens at the testing temperature, all the specimens were tempered for 14 to 15 hr at the testing temperature.

The tensile ductility of all the microstructures increases with the decrease in strength that accompanies increasing test temperature.

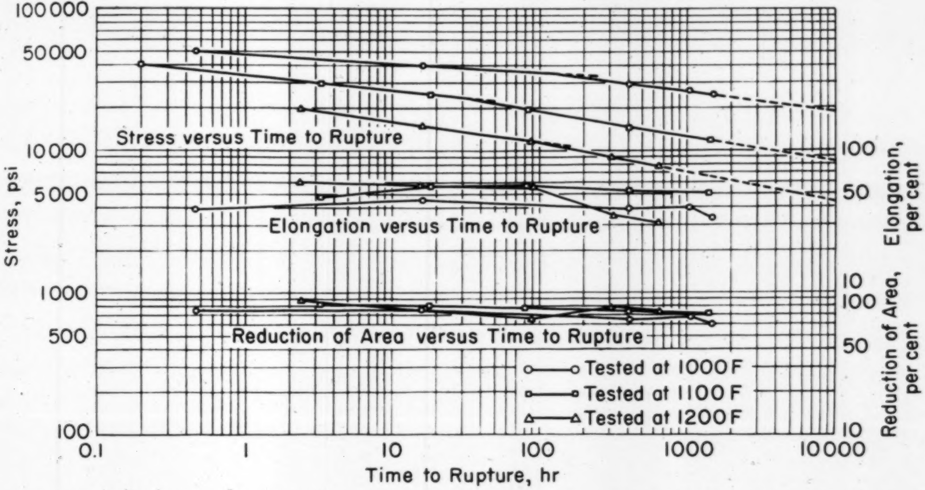

FIG. 10.—Creep-Rupture Data for a 2 per cent Chromium, ½ per cent Molybdenum Stee Heat-Treated to Coarse Pearlite and Tempered at 1100 F.

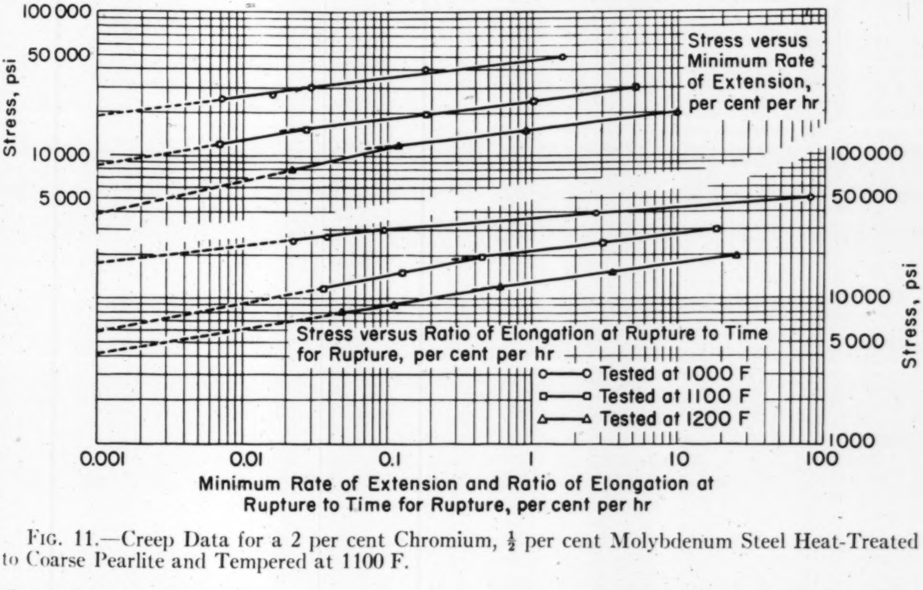

FIG. 11.—Creep Data for a 2 per cent Chromium, ½ per cent Molybdenum Steel Heat-Treated to Coarse Pearlite and Tempered at 1100 F.

Creep-Rupture Tests:

The creep-rupture data are summarized in Table V and are plotted in Figs. 10 to 21. The 100-hr creep-rupture strengths at 1000 F show marked differences among the microstructures, there being 32,000 psi difference between the 100-hr strength of the weakest microstructure, fine pearlite, and that of the strongest, upper bainite. In decreasing order of 100-hr rupture strengths at 1000 F, the microstructures are upper bainite, lower bainite, martensite tempered at 1100 F, martensite tempered at 1200 F, coarse pearlite, and fine pearlite. At 1100 F the differences between the 100-hr creep-rupture strengths of the different microstructures are smaller than at 1000 F, the strength of the pearlites being about the same, about 20,000 psi, and that of the acicular transformation products about the same, 24,200 to 26,800 psi. At 1200 F only 1600 psi separates the 100-hr strength of the strongest and the weakest microstructure.

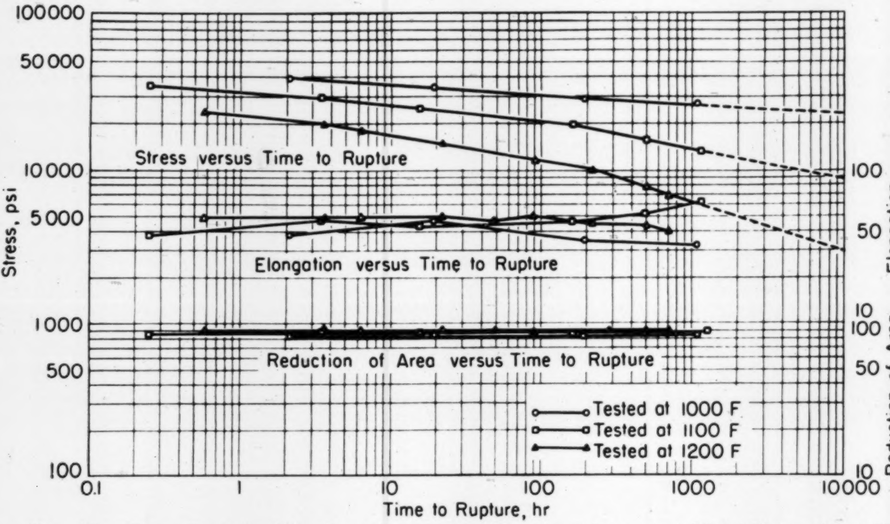

FIG. 12.—Creep-Rupture Data for a 2 per cent Chromium, ½ per cent Molybdenum Steel Heat-Treated to Fine Pearlite and Tempered at 1100 F.

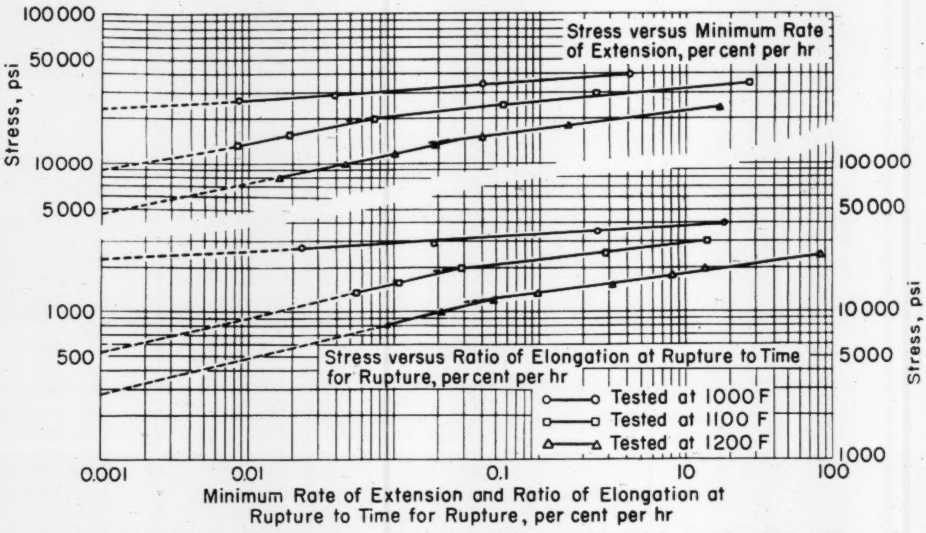

FIG. 13.—Creep Data for a 2 per cent Chromium, ½ per cent Molybdenum Steel Heat Treated to Fine Pearlite and Tempered at 1100 F.

The data in Table V show that at 1000 F the 1000-hr creep-rupture strengths of the acicular transformation products tempered at 1100 F is 9000 to 12,000 psi higher than that of the pearlites; the creep-rupture strength of the martensite tempered at 1200 F is only about 6000 psi higher than that of the pearlite. At 1100 F the acicular transformation products have only about a 3000-psi advantage in 1000-hr creep-rupture strength over the pearlites, and at 1200 F the greatest difference in the creep-rupture strengths of any two of the microstructures is 1200 psi.

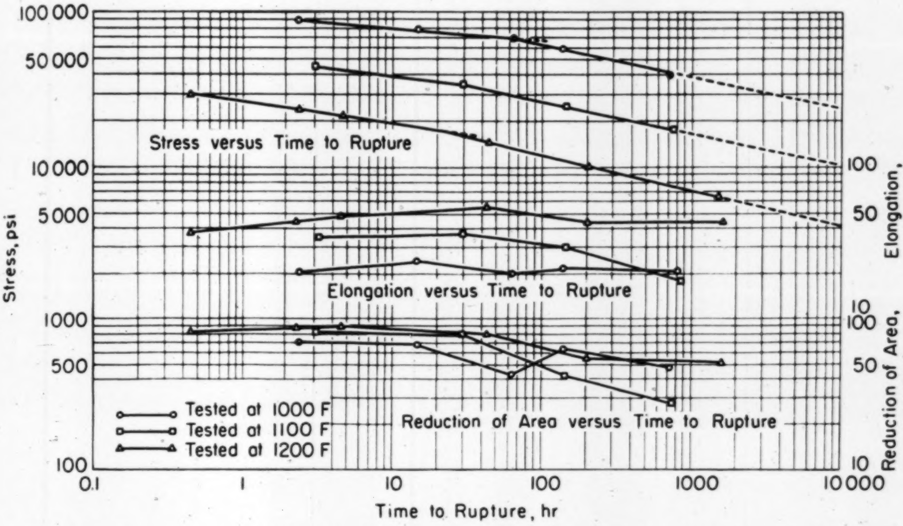

FIG. 14.—Creep-Rupture Data for a 2 per cent Chromium, ½ per cent Molybdenum Steel Heat-Treated to Upper Bainite and Tempered at 1100 F.

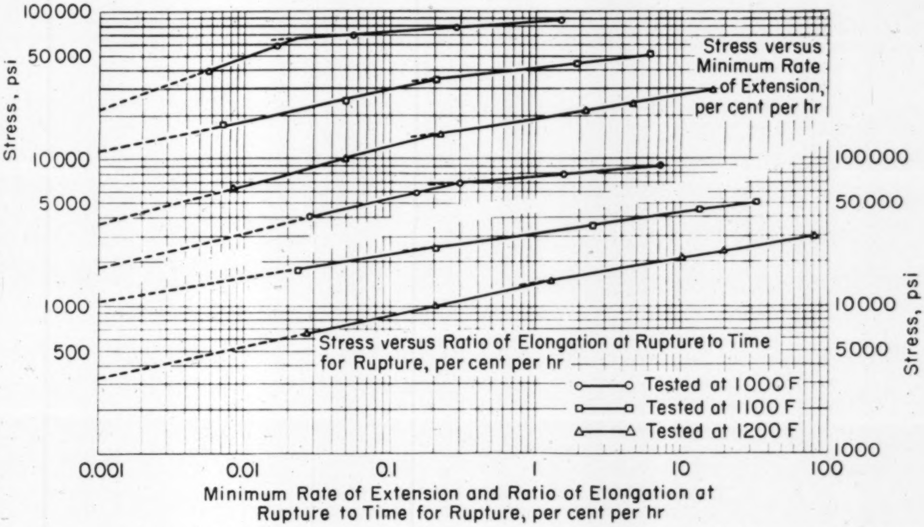

FIG. 15.—Creep-Rupture Data for a 2 per cent Chromium, ½ per cent Molybdenum Steel Heat-Treated to Upper Bainite and Tempered at 1100 F.

At 1000 F the acicular transformation products have slightly higher 10,000-hr creep-rupture strengths than the pearlites, but at 1100 and 1200 F, this small difference decreases.

microstructures (Table V). The stresses for the fine pearlite, the upper and the lower bainite, and the martensite tempered at 1200 F are about 25 per cent lower than that of the martensite tempered at 1100 F. At 1100 F the upper and the lower bainite show the highest stress

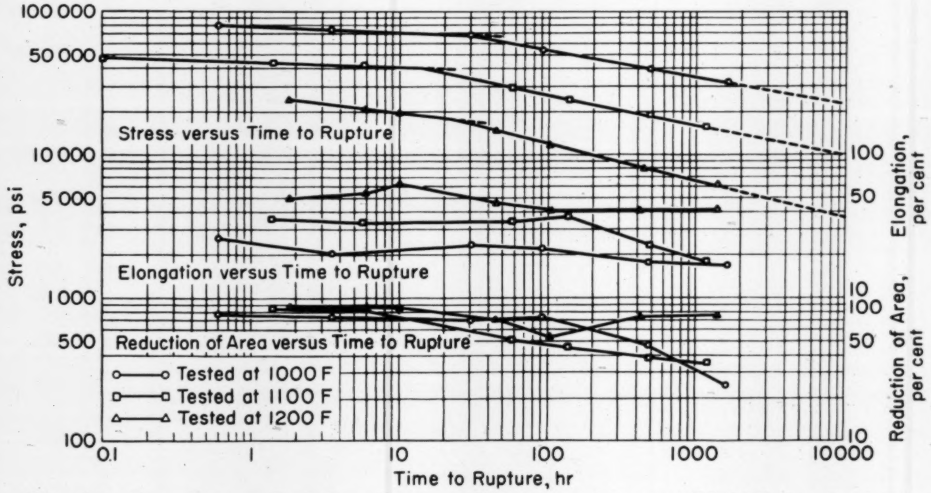

FIG. 16.—Creep-Rupture Data for a 2 per cent Chromium, ½ per cent Molybdenum Steel Heat Treated to Lower Bainite and Tempered at 1100 F.

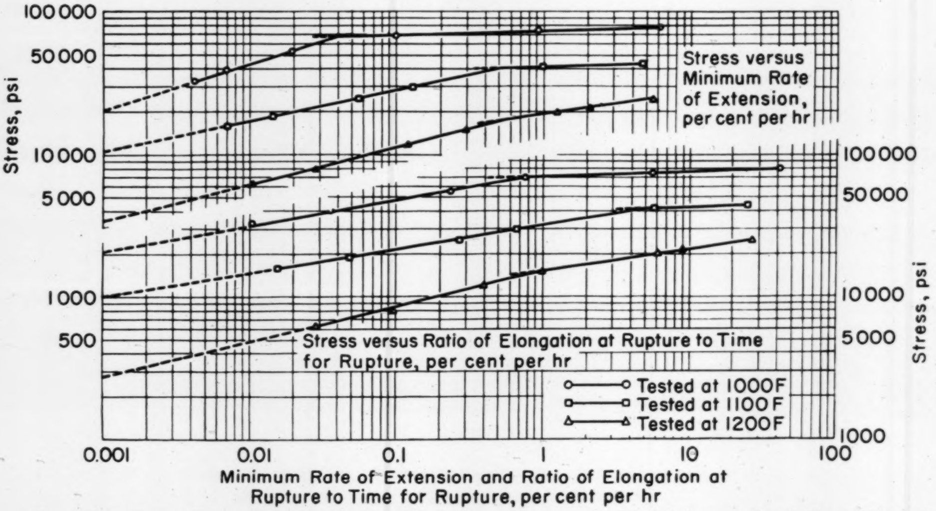

FIG. 17.—Creep Data for a 2 per cent Chromium, ½ per cent Molybdenum Steel Heat Treated to Lower Bainite and Tempered at 1100 F.

The stress for a minimum creep rate of 0.001 per cent per hour at 1000 F for the martensite tempered at 1100 F is significantly higher than those for the other for the aforementioned minimum creep rate, and the martensite tempered at 1200 F shows the lowest. At 1200 F the fine pearlite shows the highest stress for the given creep rate.

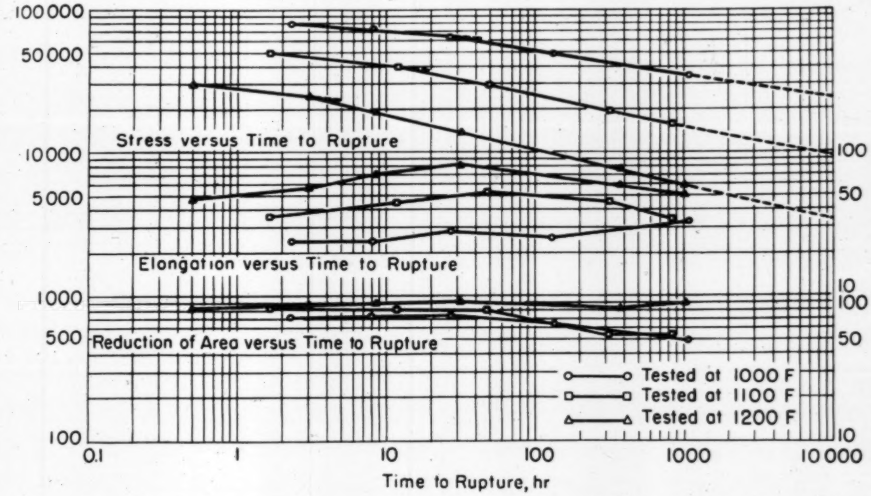

FIG. 18.—Creep-Rupture Data for a 2 per cent Chromium, ½ per cent Molybdenum Steel Heat Treated to Martensite and Tempered at 1100 F.

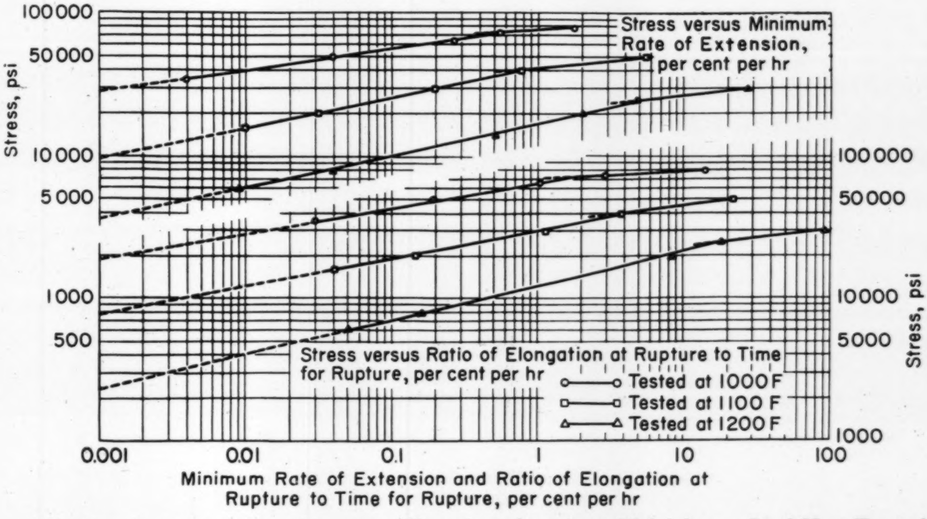

FIG. 19.—Creep Data for a 2 per cent Chromium, ½ per cent Molybdenum Steel Heat Treated to Martensite and Tempered at 1100 F.

A summary of the elevated-temperature creep-rupture data is given in Figs. 22, 23, and 24, and the general trends that have been discussed are evident from this plot. For short-time exposure at 1000 F, and to some extent at 1100 F, the strength of the acicular transformation products is higher than that of the pearlites. Of the pearlitic microstructures, the fine pearlite has a slightly higher strength than the coarse pearlite.

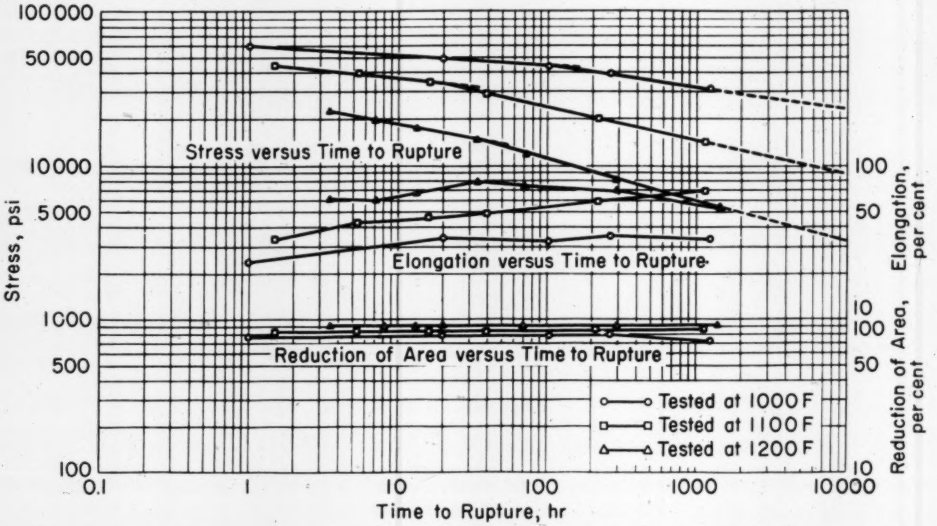

FIG. 20.—Creep-Rupture Data for a 2 per cent Chromium, ½ per cent Molybdenum Steel Heat Treated to Martensite and Tempered at 1200 F.

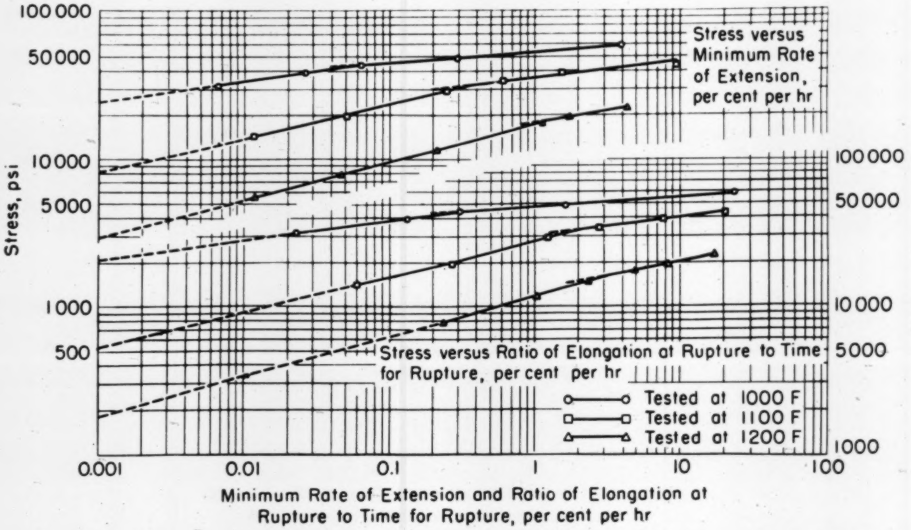

FIG. 21.—Creep Data for a 2 per cent Chromium, ½ per cent Molybdenum Steel Heat Treated to Martensite and Tempered at 1200 F.

Of the acicular transformation products, the upper bainite has the highest strenghts. For long-time exposure at 1000, 1100, and 1200 F and for short time exposure at 1100 and 1200 F, the upper bainite is still the strongest structure, but the difference between the strength of the strongest and of the weakest structure is small.

Some indication of the effect of increasing exposure time and increasing temperature in minimizing the differences between the strengths of the different microstructures may be gained from the photomicrographs of Figs. 25 to 30. Illustrated in these figures are the microstructural changes that occur as the test temperature is increased. With the exception of the coarse pearlite which changes the least, all the microstructures tend to become similar with increasing exposure time and temperature in the range 1000 to 1200 F. It is interesting to note from Figs. 22, 23, and 24 that the decrease in strength with increasing temperature of the coarse pearlite is less than that of the other microstructures.

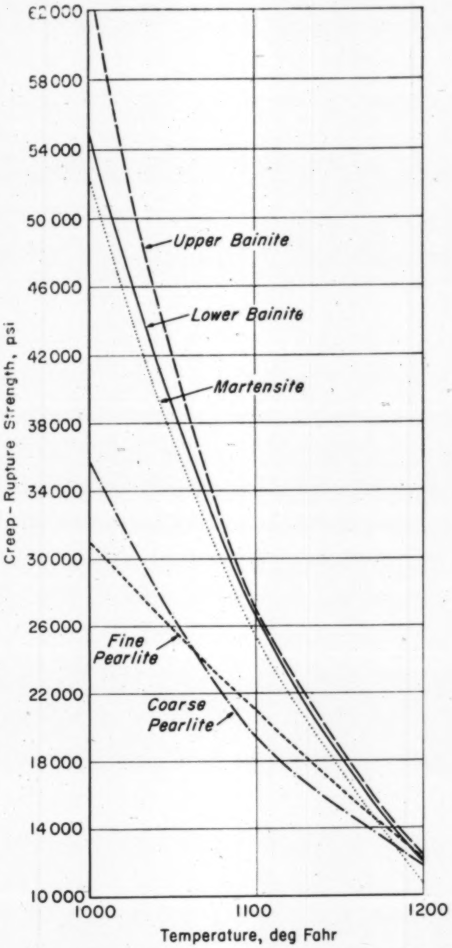

FIG. 22.—100-hr Creep-Rupture Strength of a 2 per cent Chromium, ½ per cent Molybdenum Steel Heat-Treated to the Indicated Microstructures.

The results of the present investigation for short-time exposure at the lowest temperature are in general agreement with the data reported by other investigators (**1, 2, 6, 7**). As was mentioned previously, most of the work reported by foreign investigators is for relatively short-time testing[5] at temperatures of about 932 (500 C). The results of these other investigations show a marked effect of microstructure on the short-time creep strength at temperatures of 750 F to about 950 or 1000 F, bainitic microstructures having the highest strength. When the test temperature approached 1100 F, however, the effect of microstructure on the creep strength became negligible.

SUMMARY

The results of the present investigation on a 2 per cent chromium, ½ per cent molybdenum steel may be summarized as follows:

For short-time exposure (100 hr) at a temperature of 1000 F, there is a significant effect of microstructure on the creep-rupture strength of steel. Upper bainite has the highest creep-rupture strength, and coarse pearlite has the lowest creep-rupture strength. The 100-hr rupture strengths of the different microstructures at 1000 F fall in about the same relative order as the room- and elevated-temperature tensile strengths. The 1000-hr rupture strengths at 1000 F show much smaller differences between the microstructures than do the 100-hr rupture strengths, and the 10,000-hr strengths show only slight differences.

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[5] The creep limits reported in the German literature are obtained by the DVM method and are defined as the stress under which the rate of creep attains a value of 10 × 10^{-4} per cent per hour between the 25th and the 35th hour; those reported in the French literature are obtained by the Veritas method and are defined as the stress under which the rate of creep attains a value of 5 × 10^{-4} per cent per hour between the 25th and the 35th hour.

When the test temperature is increased to 1100 and 1200 F, the 100-hr rupture strengths still indicate a significant effect of microstructure, the 1000-hr strengths indicate a small effect, and the 10,000-hr strengths indicate an even smaller effect.

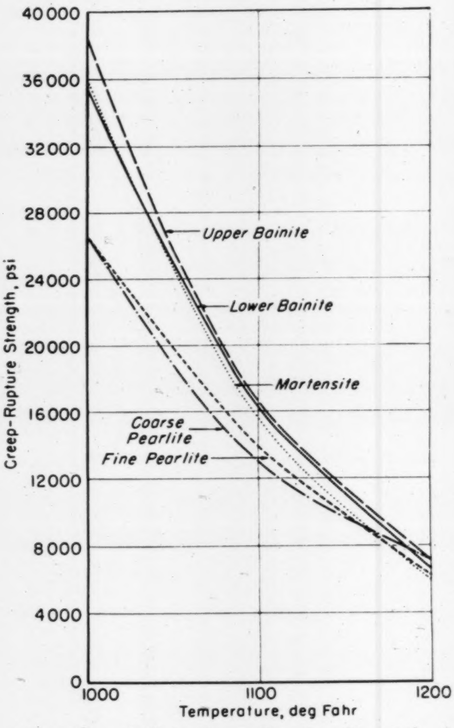


FIG. 23.—1000-hr Creep-Rupture Strength of a 2 per cent Chromium, ½ per cent Molybdenum Steel Heat Treated to the Indicated Microstructures.

In general, when there is a difference in the creep-rupture strengths of the microstructures at 1000, 1100, and 1200 F, the upper bainite has the highest strength.

These results appear to indicate that as the test temperature increases or as the time at a particular test temperature increases, the different initial microstructures become more nearly the same and, therefore, that the strengths of the microstructures for a given exposure time also approach a constant value. Thus, for applications in which the exposure time is short, such as in rocket projectiles and certain jet-engine parts, the initial microstructure is an important factor in obtaining maximum strength at temperatures up to about 1100 F. On the other hand, for long-time elevated-temperature service, such as in steam turbines, there is little advantage in elevated-temperature strength to be gained by selecting one microstructure over another. It is believed that these statements are applicable to most heat-

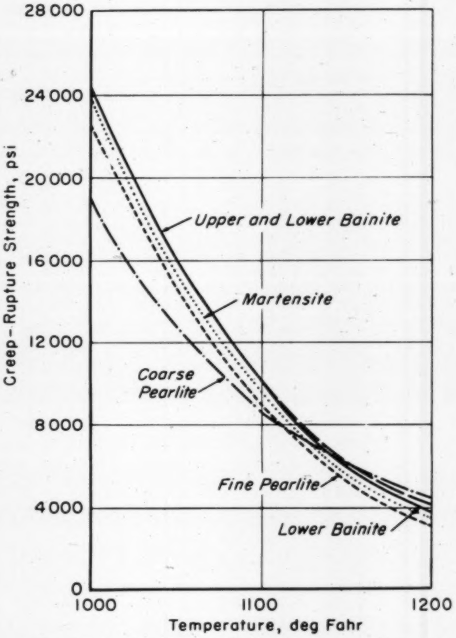
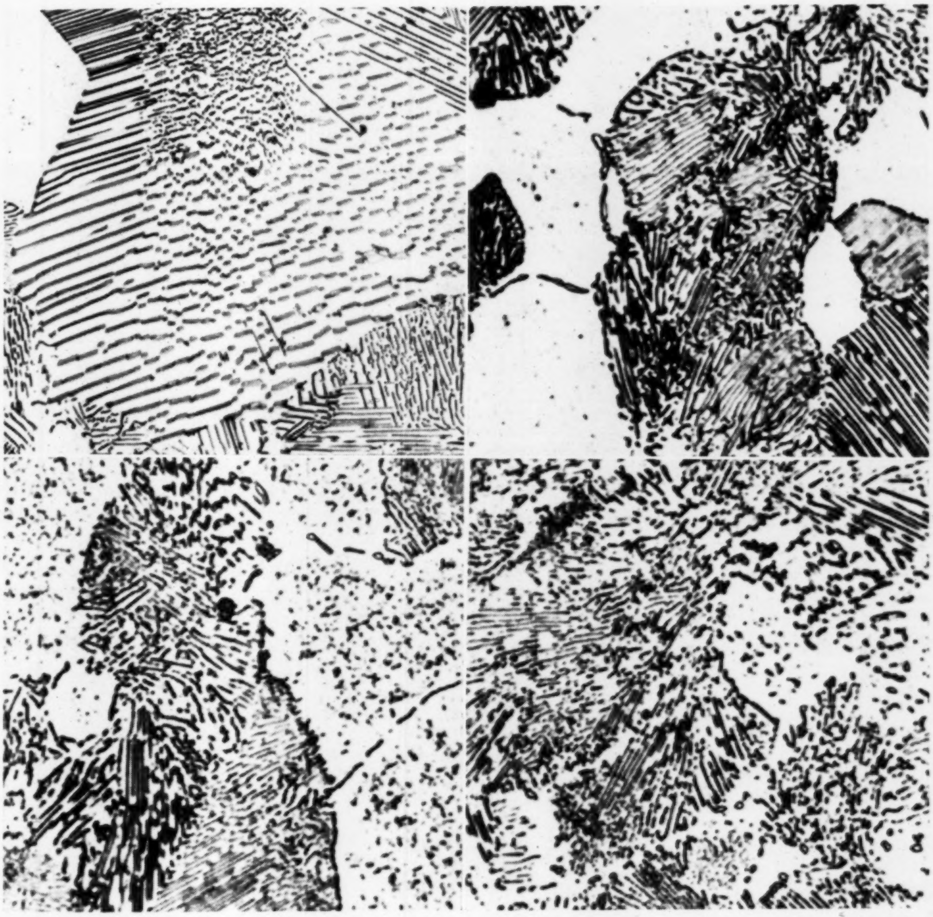


FIG. 24.—10,000-hr Creep-Rupture Strength of a 2 per cent Chromium, ½ per cent Molybdenum Steel Heat-Treated to the Indicated Microstructures.

(*a*) Original microstructure.

(*b*) Microstructure after rupturing in 1505 hr at 1000 F. Stress—25,000 psi.



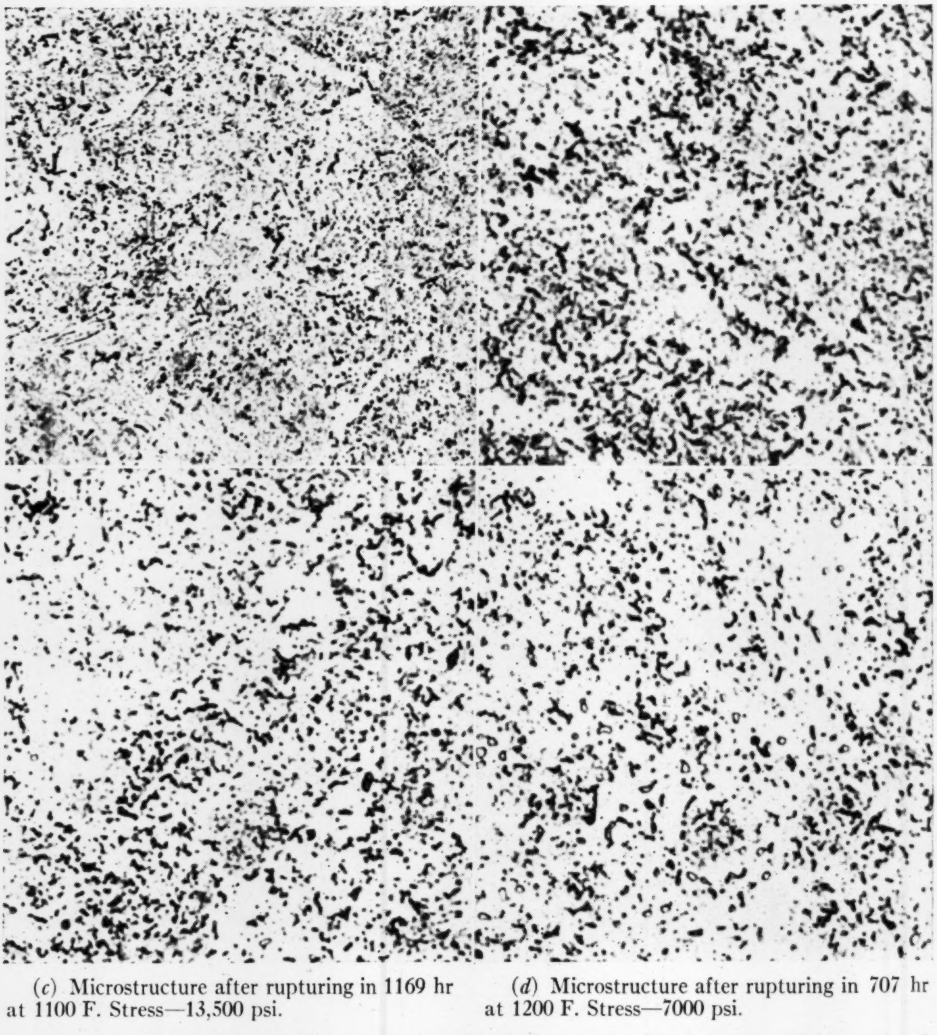
(*c*) Microstructure after rupturing in 1414 hr at 1100 F. Stress—12,000 psi.

(*d*) Microstructure after rupturing in 660 hr at 1200 F. Stress—7000 psi.

FIG. 25.—Microstructural Changes That Occurred During the Creep-Rupture Testing of a 2 per cent Chromium, ½ per cent Molybdenum Steel Heat-Treated to Coarse Pearlite and Tempered at 1100 F, Picral Etch (× 1000).

(*a*) Original microstructure.

(*b*) Microstructure after rupturing in 1093 hr at 1000 F. Stress—27,000 psi.



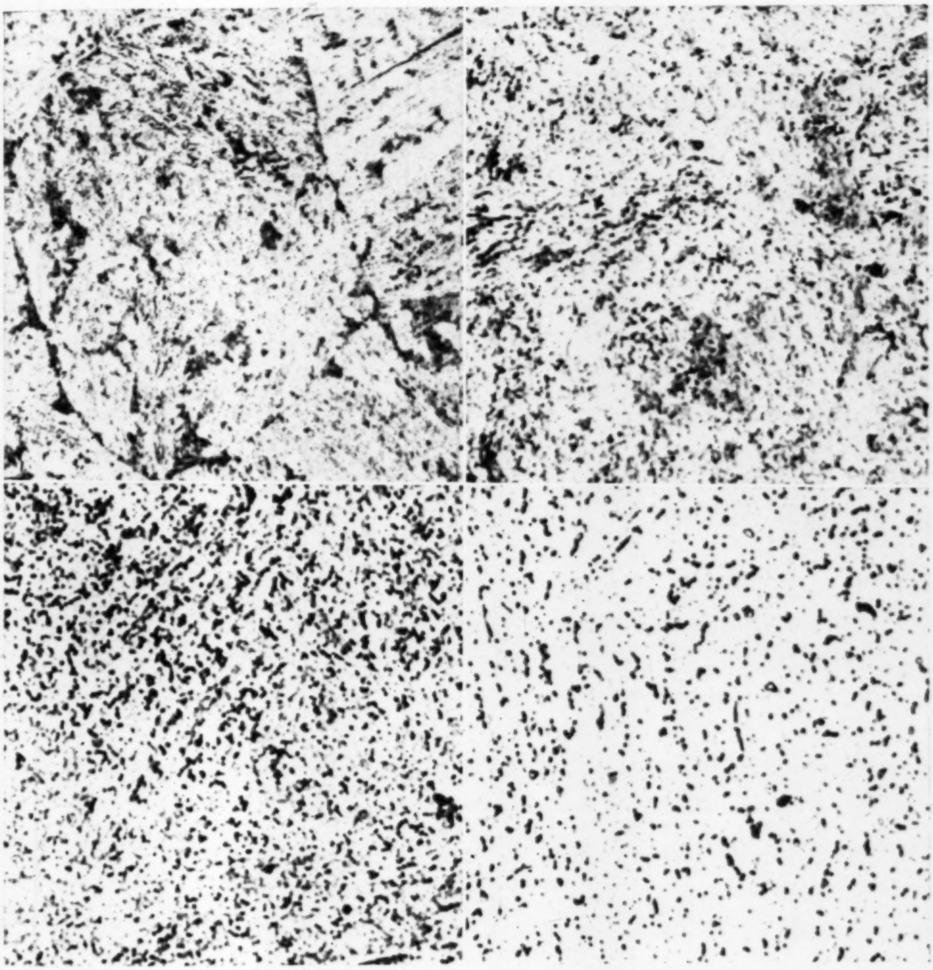
(*c*) Microstructure after rupturing in 1169 hr at 1100 F. Stress—13,500 psi.

(*d*) Microstructure after rupturing in 707 hr at 1200 F. Stress—7000 psi.

FIG. 26.—Microstructural Changes That Occurred During the Creep-Rupture Testing of a 2 per cent Chromium, $\frac{1}{2}$ per cent Molybdenum Steel Heat-Treated to Fine Pearlite and Tempered at 1100 F, Picral Etch (× 1000).

(*a*) Original microstructure.

(*b*) Microstructure after rupturing in 733 hr at 1000 F. Stress—40,000 psi.



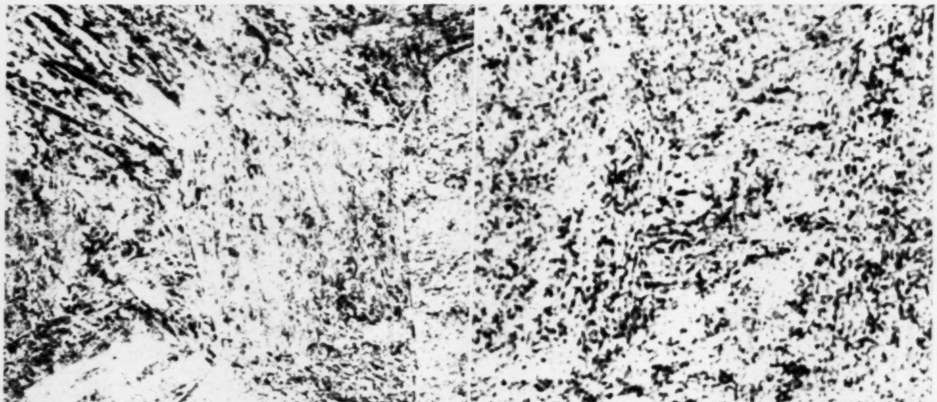
(*c*) Microstructure after rupturing in 765 hr at 1100 F. Stress—17,700 psi.

(*d*) Microstructure after rupturing in 1628 hr at 1200 F. Stress—6600 psi.

FIG. 27.—Microstructural Changes That Occurred During the Creep-Rupture Testing of a 2 per cent Chromium, ½ per cent Molybdenum Steel Heat-Treated to Upper Bainite and Tempered at 1100 F, Picral Etch (× 1000).

(*a*) Original microstructure.

(*b*) Microstructure after rupturing in 1615 hr at 1000 F. Stress—33,000 psi.



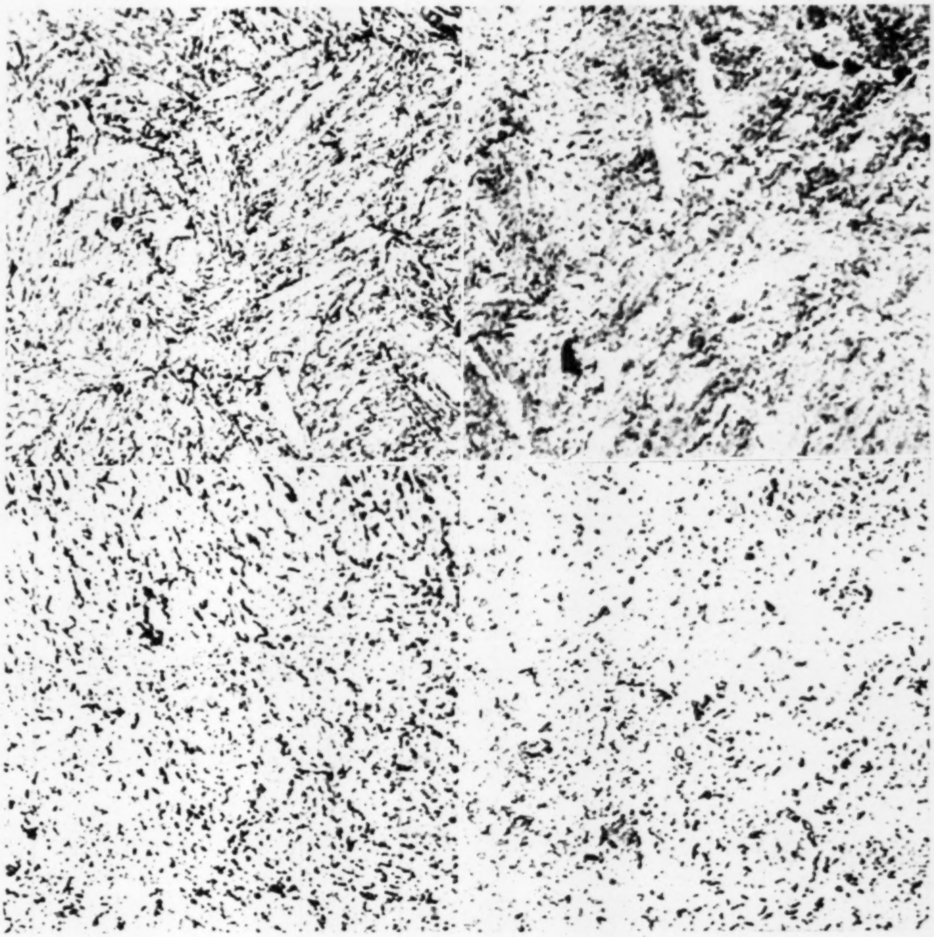
(*c*) Microstructure after rupturing in 1181 hr at 1100 F. Stress—16,000 psi.

(*d*) Microstructure after rupturing in 1403 hr at 1200 F. Stress—6350 psi.

FIG. 28.—Microstructural Changes That Occurred During the Creep-Rupture Testing of a 2 per cent Chromium, $\frac{1}{2}$ per cent Molybdenum Steel Heat-Treated to Lower Bainite and Tempered at 1100 F, Picral Etch (× 1000).

(*a*) Original microstructure.

(*b*) Microstructure after rupturing in 1102 hr at 1000 F. Stress—35,000 psi.



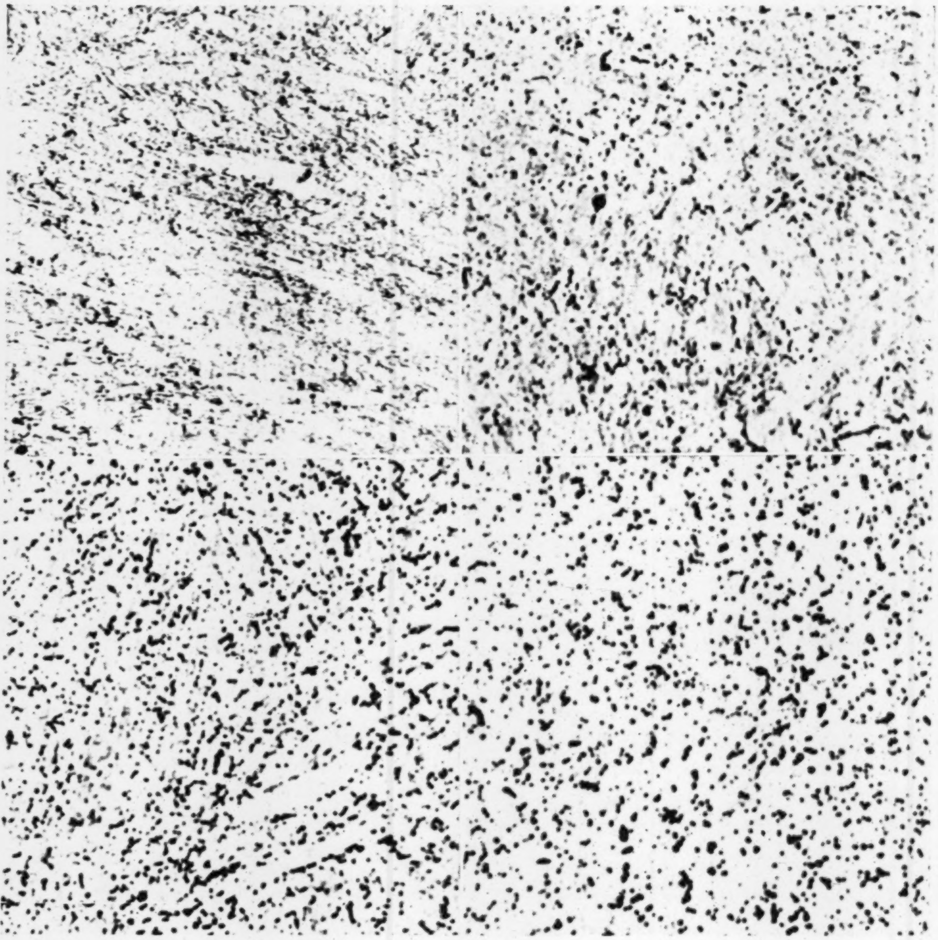
(*c*) Microstructure after rupturing in 841 hr at 1100 F. Stress—16,000 psi.

(*d*) Microstructure after rupturing in 1015 hr at 1200 F. Stress—6000 F.

FIG. 29.—Microstructural Changes That Occurred During the Creep-Rupture Testing of a 2 per cent Chromium, ½ per cent Molybdenum Steel Heat-Treated to Martensite and Tempered at 1100 F, Picral Etch (× 1000).

(*a*) Original microstructure.

(*b*) Microstructure after rupturing in 1277 hr at 1000 F. Stress—32,000 psi.



(*c*) Microstructure after rupturing in 1140 hr at 1100 F. Stress—14,500 psi.

(*d*) Microstructure after rupturing in 1414 hr at 1200 F. Stress—5600 psi.

FIG. 30.—Microstructural Changes That Occurred During the Creep-Rupture Testing of a 2 per cent Chromium, ½ per cent Molybdenum Steel Heat-Treated to Martensite and Tempered at 1200 F, Picral Etch (× 1000).

treatable steels that are not strengthened by precipitation hardening.

In general, the room-temperature tensile properties and the elevated-temperature tensile properties of the steel investgated are functions of the initial microstructure.

Acknowledgments:

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REFERENCES

(**1**) H. Bennek and G. Bandel, "Influence of Structure as a Function of Heat-Treatment and Alloying on the Creep Resistance of Steel," *Stahl und Eisen*, Vol. 63, pp. 653, 673, 695 (1943).

(**2**) U. Wyss, "Influence of the Bainitic Structure on the Mechanical Properties of a Heat-Resistant Cr-Mo Temper-Hardening Steel," *Schweizer Archiv*, Vol. 15, p. 365 (1949); *Von Roll Mitteilungen*, Vol. 7, p. 51 (1948). (Translated and abstracted in *Metal Progress*, June, 1949, p. 868.)

(**3**) H. M. Stewart and R. A. Grange, "The Temperature Range of Martensite Formation," *Transactions*, Am. Inst. Mining and Metallurgical Engrs., Vol. 167, p. 467 (1946).

(**4**) G. K. Manning and C. H. Lorig, "The Relationship Between Transformation at Constant Temperature and Transformation During Cooling," *Transactions*, Am. Inst. Mining and Metallurgical Engrs., Vol. 167, p. 442 (1946).

(**5**) G. Delbart and R. Potaszkin, "Contribution to the Study of Steels with Intermediate Structures Produced by Interrupted Quenching," *Revue de Metallurgie*, Vol. 43, p. 84 (1946).

(**6**) G. Delbart and M. Ravery, "Contribution to the Study of the Influence of Microstructure on the Heat Resistance of Steel," *Revue de Metallurgie*, Vol. 47, p. 215 (1950). (Translated in *Metal Treatment and Drop Forging*, Vol. 17, Autumn, 1950, p. 171, and in *Metal Progress*, December, 1951, p. 62.)

(**7**) G. Delbart and M. Ravery, "Contribution to the Influence of Microstructure and Chemical Composition on the Creep Resistance of Chromium-Molybdenum Steels," *Comptes Rendus*, Vol. 232, January 3, 1951, p. 67.

SHORT-TIME TENSION AND CREEP-RUPTURE PROPERTIES OF HARDENED 1040, 4340, AND Ni-Cr-Mo-V STEELS UP TO 1000 F*

By G. V. Smith[1] and W. B. Seens[1]

Synopsis

Short-time tensile properties at 80, 500, 700, 850, and 1000 F and creep-rupture properties at 850 and 1000 F are reported for 1040, 4340, and Ni-Cr-Mo-V (0.40 per cent carbon) steels heat treated to a tensile strength of 150,000 psi at room temperature. The 1040 steel was also tested in creep-rupture at 500 and 700 F.

After the completion, several years ago,[2] of a study of the mechanical properties of hardened 4340 and nickel-chromium-molybdenum-vanadium steels at temperatures up to 700 F, it became apparent that there is considerable interest in the properties of such steels at even higher temperatures. Although this previous study had been conducted on material quenched and tempered to a tensile strength of 200,000 psi at room temperature, it was deemed necessary, if higher temperatures were to be studied, to conduct the tests on material at a somewhat lower strength; otherwise the test temperatures would exceed the tempering temperature. Since interest seemed to lie in test temperatures up to 1000 F, a strength level of 150,000 psi was considered appropriate.

The same two grades previously studied were included and, in addition, 1040 steel was subsequently added to the program, because of its freedom from strategic alloying elements. However, 1040 steel does not approach the hardenability of the two alloy grades and hence would be suited only for relatively thin sections. All steels were tested in creep rupture at 850 and 1000 F, and since the 1040 steel had not been included in the previous tests, it was also tested at 500 and 700 F. The tests of the 1040 steel at all temperatures were carried out at the 150,000 psi level; even so, the tests at 850 and 1000 F were above the tempering temperature (840 F) for this material. Short-time tension tests were made of all steels at 80, 500, 700, 850, and 1000 F.

Materials and Procedure

The analyses and heat treatment of the test steels are given in Table I. The Ni-Cr-Mo-V steel is the identical one of the previous study[2] and represents the $\frac{1}{2}$-in. thick rolled product of a 300-lb induction furnace heat. The 1040 steel was of open-hearth manufacture and the

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13–18, 1954.

[1] Research Laboratory, United States Steel Corp., Kearny, N. J.

[2] G. V. Smith, W. B. Seens, and E. J. Dulis, "Hardened Alloy Steel for Service Up to 700 F," *Proceedings*, Am. Soc. Testing Mats., Vol. 50, pp. 882–892 (1950).

4340 of electric furnace manufacture; both were received as $\frac{1}{2}$-in. round bars. All steels were oil-quenched after 1 hr at the austenitizing temperature and water-quenched after 2 hr at the tempering temperature. The austenitizing and tempering temperatures used are listed in Table I. Specimens were heat-treated in a rough-machined condition and finish-machined after heat treatment. The proper tempering temperatures were established in a preliminary survey. Tension test specimens had a reduced section of 0.250 in., and the elongation was measured after fracture over a 1-in. gage length. The creep-rupture specimens had a reduced section of 0.200 in., and the elongation was measured over a 0.8-in. gage length. The creep-rupture tests were carried out at a series of stresses chosen to permit establishment of the 1000-hr strength without undue extrapolation. Creep strains were measured by sighting with a telescope through a window in the furnace wall on a "wire-tube" extensometer mounted on the test specimen.[3]

TABLE I.—CHEMICAL COMPOSITION AND HEAT TREATMENT OF TEST STEELS.

Grade	Composition, per cent								
	Carbon	Manganese	Phosphorus	Sulfur	Silicon	Nickel	Chromium	Molybdenum	Vanadium
1040	0.41	0.77	0.018	0.035	0.22	...	...	...	...
4340	0.39	0.71	0.012	0.016	0.29	1.82	0.72	0.28	...
Ni-Cr-Mo-V	0.40	0.21	0.015	0.015	0.16	2.0	0.97	0.37	0.18

HEAT TREATMENT

Grade	Austenitizing Temperature,[a] deg Fahr	Tempering Temperature,[b] deg Fahr
1040	1550	840
4340	1550	1170
Ni-Cr-Mo-V	1600	1245

[a] 1 hr at temperature.
[b] 2 hr at temperature.

RESULTS AND DISCUSSION

Initial Microstructures:

The microstructures of the test steels as quenched and tempered to a tensile strength of approximately 150,000 psi at room temperature are shown in Fig. 1. Through-hardening was effected in the two alloy steels, and the microstructures are typically tempered martensite. The 1040 steels appeared to have a trace of nonmartensitic transformation product and a slightly coarser austenitic grain size.

Short-Time Tension Tests:

Two or more tension tests were carried out on each steel at 80, 500, 700, 850, and 1000 F, with results summarized in Table II and Fig. 2. It will be noted that the tensile strength of the 4340 steel at room temperature was 143,000 psi, slightly lower than the desired 150,000. This discrepancy arose because the tempering treatment was established on the basis of hardness measurements. The replicate tests showed good agreement.

Except for a slight rise in the tensile strength of the 1040 steel at 500 F, which may or may not be significant (strain-aging?), the yield and tensile strengths decreased with increasing temperature. At the same time, the elongation and reduction of area of the steels increased. If account is taken of the difference in properties at room temperature, the 4340 and Ni-Cr-Mo-V steels on being heated retained their strength to about the same degree, but the 1040 steel was significantly inferior at the higher test temperatures of 850 and 1000 F, both of which exceeded the tempering temperature used for this grade.

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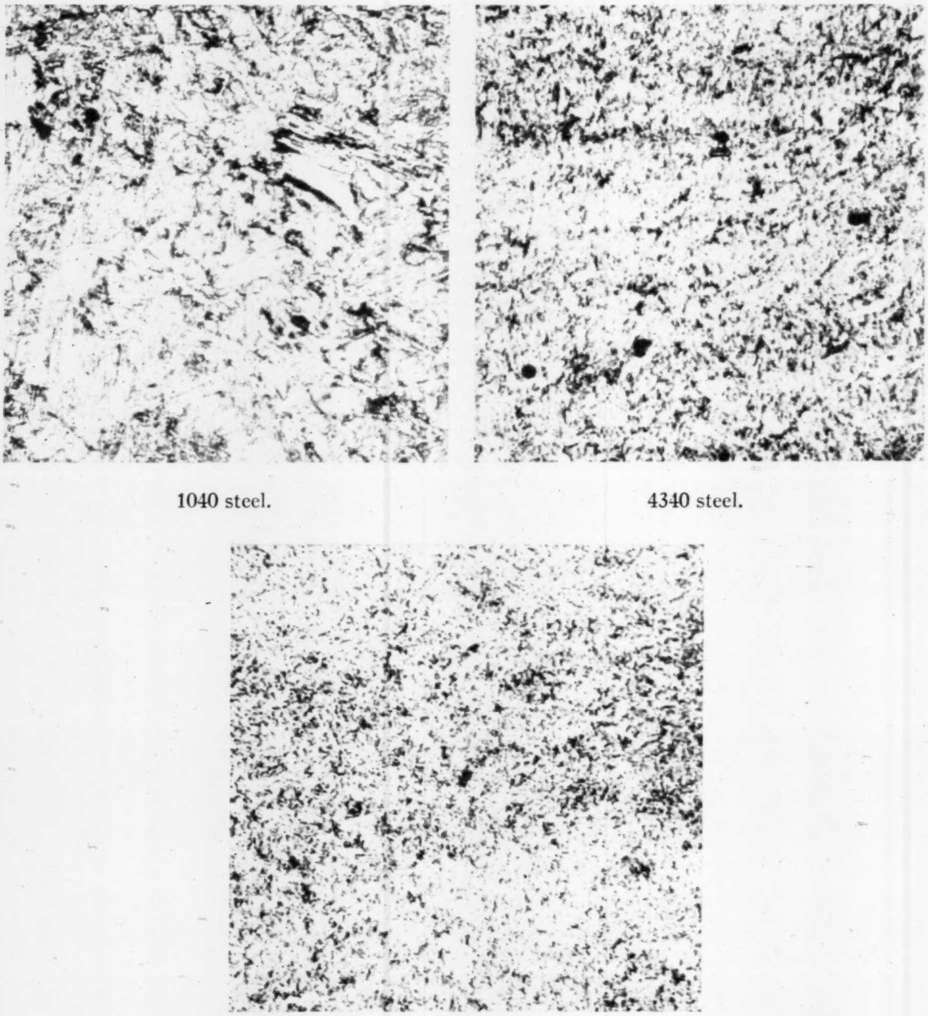
[3] J. A. Fellows, E. Cook, and H. S. Avery, "Precision in Creep Testing," *Transactions*, Am. Inst. Mining and Metallurgical Engrs., Vol. 150, p. 358 (1942).



1040 steel.

4340 steel.

Ni-Cr-Mo-V steel.

FIG. 1.—Initial Microstructures of Steels. Etched in picral (× 1000).

Creep-Rupture Tests:

The results of the creep-to-rupture

TABLE II.—RESULTS OF SHORT-TIME TENSILE TESTS.

Average of two or more tests, 0.25 in. in diameter.

Temperature, deg Fahr	Steel	0.2% Offset Yield Strength, psi	Tensile Strength, psi	Elongation in 1 in., per cent	Reduction of Area, per cent
80..............	1040	135 000	149 000	18.5	65
	4340	129 000	143 000	20.5	62
	Ni-Cr-Mo-V	145 500	151 000	18.5	60
500	1040	113 000	152 000	36.0	77
	4340	107 000	139 500	20.5	53
	Ni-Cr-Mo-V	117 000	142 000	20.5	60
700............	1040	88 000	114 000	35.0	85
	4340	96 000	122 000	25.0	72
	Ni-Cr-Mo-V	102 000	125 000	23.5	68
850..............	1040	56 000	80 500	39.5	90
	4340	85 500	103 000	26.0	76
	Ni-Cr-Mo-V	93 500	110 000	23.0	74
1000..............	1040	26 000	50 000	51.0	91
	4340	58 000	80 000	34.0	87
	Ni-Cr-Mo-V	69 500	87 000	27.5	81

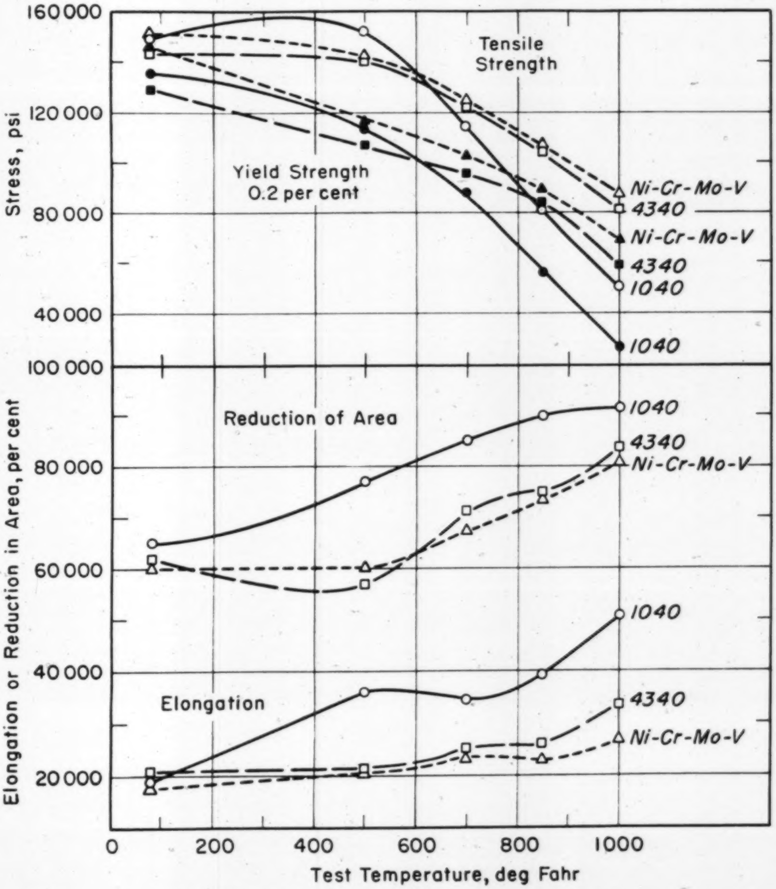


FIG. 2.—Variation of Short-Time Tensile Properties with Test Temperature.

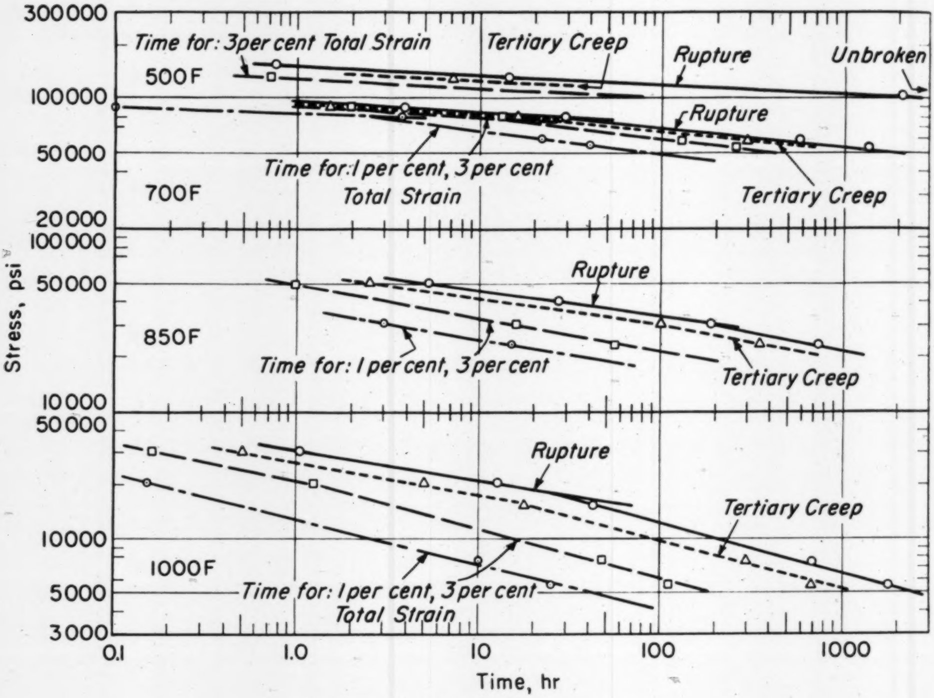


FIG. 3.—Design Chart—1040 Steel.

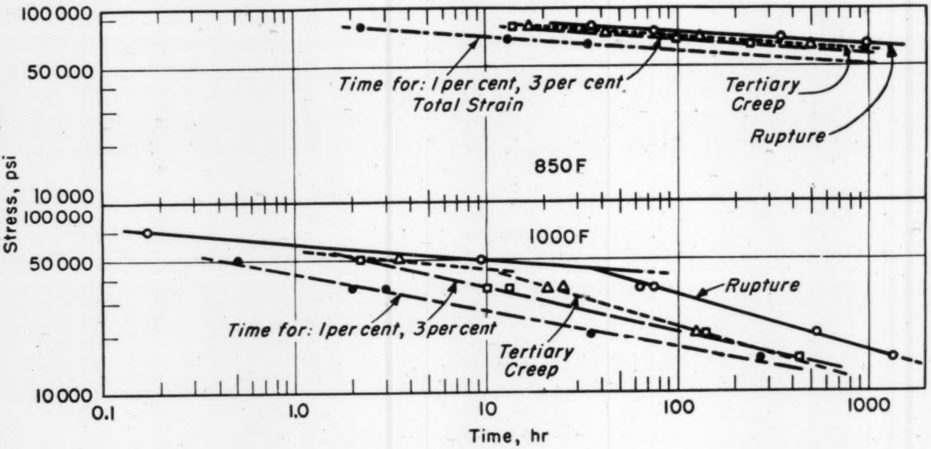


FIG. 4.—Design Chart—4340 Steel.

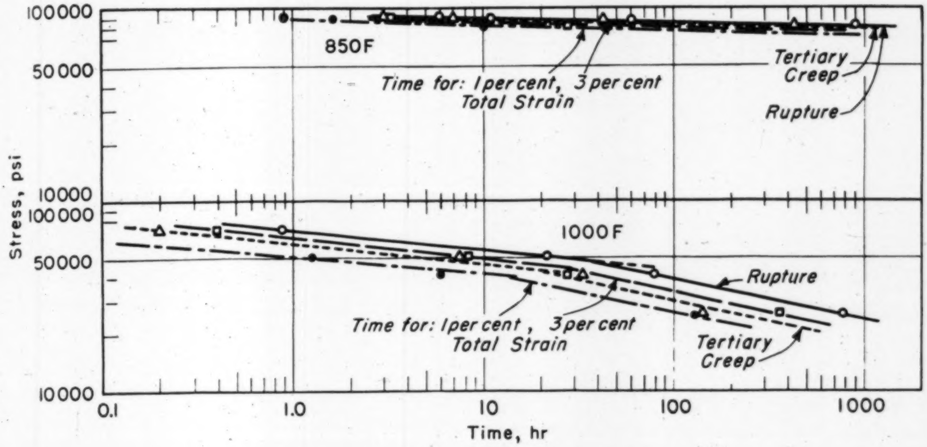


FIG. 5.—Design Chart—Ni-Cr-Mo-V Steel.

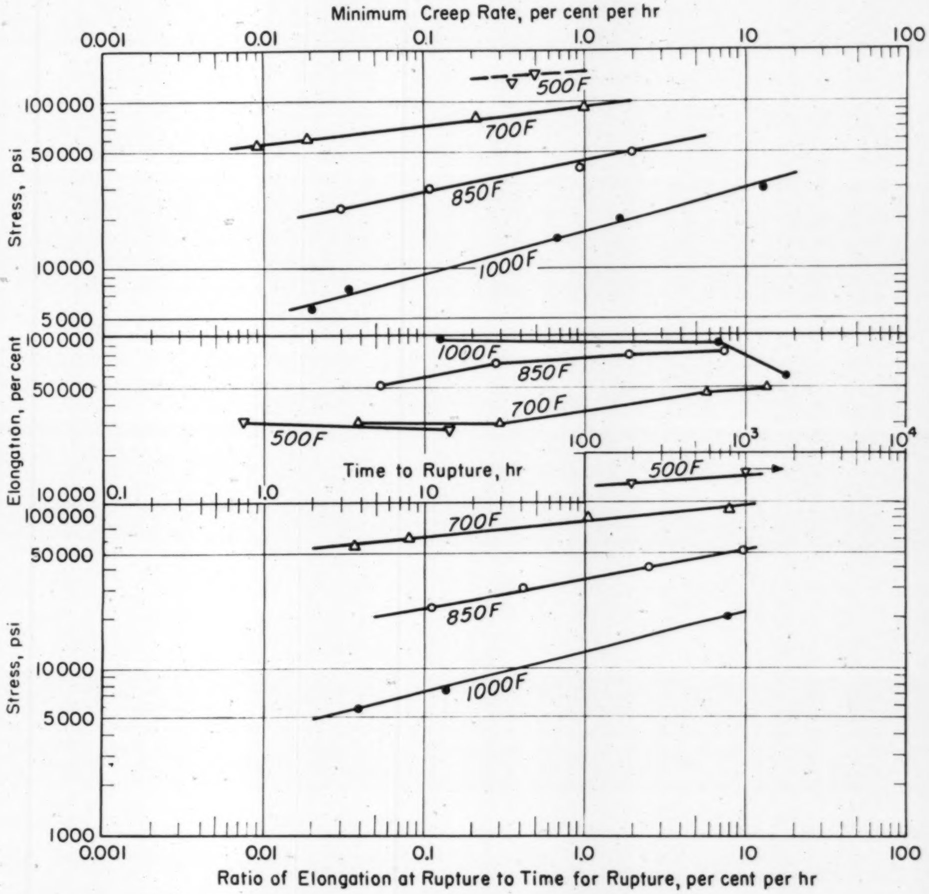


FIG. 6.—Creep Rate and Ductility Characteristics of 1040 Steel.

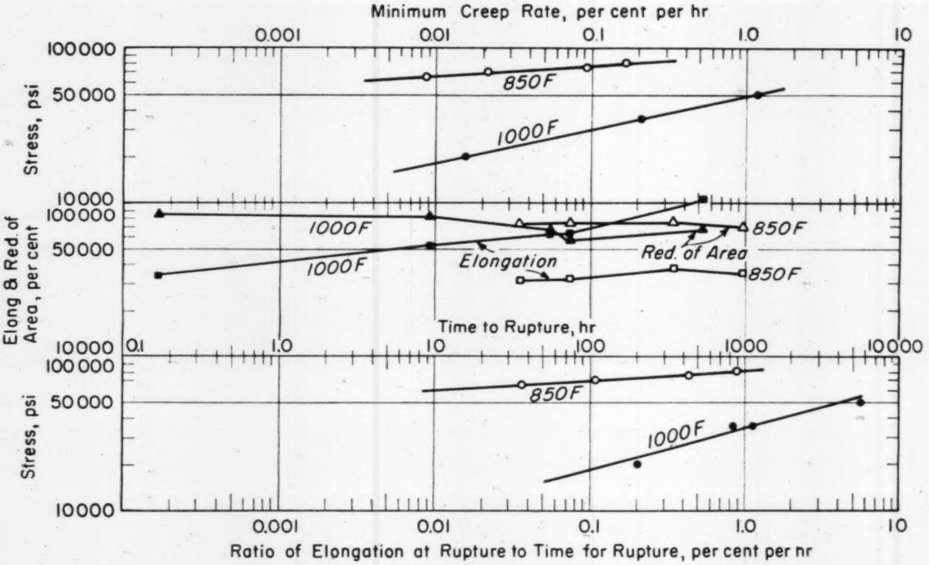


FIG. 7.—Creep Rate and Ductility Characteristics of 4340 Steel.

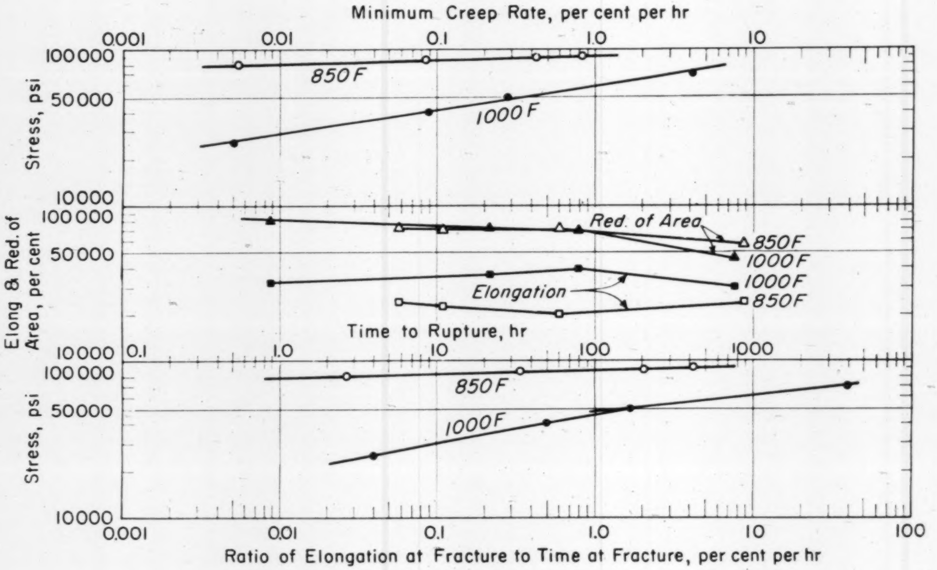


FIG. 8.—Creep Rate and Ductility Characteristics of Ni-Cr-Mo-V Steel.

tests are presented in the form of so-called "design charts" in Figs. 3, 4, and 5. On each of the charts is shown the time for 1 and 3 per cent total strain as well as the time for beginning of tertiary creep (accelerating-rate stage) and the time for rupture. Minimum creep rate and ductility data for the steels are shown in Figs. 6, 7, and 8.[4]

With increasing temperature the slopes of the curves of the design charts increased as did the spread between the curves of a family. Similarly the slopes of the minimum and average creep rate curves increased with increasing temperature. All steels showed good ductility even at the longest rupture times, in contrast to some tendency for brittleness in the previous tests of material heat-treated to the 200,000-psi strength level.

As a basis for comparison of the three steels, the stresses for rupture in 1000 hr and for a mininum creep rate of 0.01 per cent per hour are listed in Table III. The strength of the 1040 steel in terms either of rupture time or creep rate was greatly inferior to the alloy steels at the two temperatures, 850 and 1000 F, at which they were all tested. As mentioned earlier, both of these temperatures exceeded the tempering temperature of the 1040 steel. Of the two alloy grades, the Ni-Cr-Mo-V steel was significantly the superior, and more so at 1000 F than at 850 F. This superiority of Ni-Cr-Mo-V steel had been observed in the previous tests at the 200,000-psi level of strength.[2]

The relation of the 1000-hr rupture strength to the yield strength in short-time tests is of interest as a rough indicator of whether creep should be considered in design. In the previous study of the 4340 and Ni-Cr-Mo-V steels at a strength level of 200,000 psi, it was found that the yield strength was less than the 1000-hr rupture strength up to about 700 F. In the present study, it was found, as is to be expected, that the rupture strength lies below the yield strength at the two higher test temperatures. However, in the case of the 1040 steel in the present study, the 1000-hr rupture strength is less than the yield strength even at the lowest test temperature of 500 F.

After fracture, the test specimens were sectioned longitudinally through the fracture, nickel-plated, mounted, polished, and examined for the mode of fracture as well as for changes in microstructure. All fractures appeared to be transgranular but tended toward intergranular at the longest test time at the highest temperature. Spheroidization was observed and was more pronounced the higher the test temperature and the longer the test time. Photomicrographs near the fracture surface of the longest-time fracture at 1000 F for each of the three steels are shown in Fig. 9.

TABLE III.—RESULTS OF CREEP-RUPTURE TESTS.

Grade	Stress for Rupture in 1000 hr, psi			
	500 F	700 F	850 F	1000 F
1040	108 000	56 000	21 500	6 400
4340	...	...	65 000	16 300
Ni-Cr-Mo-V	...	...	80 000	23 500

Grade	Stress for Minimum Creep Rate of 0.01 per cent per hr, psi			
	500 F	700 F	850 F	1000 F
1040	...	55 000	18 500	5 200
4340	...	...	65 000	18 000
Ni-Cr-Mo-V	...	...	80 000	29 000

Summary

With increasing temperature of test, the yield and tensile strengths of all three steels decreased, except for a slight intermediate rise at 500 F in the tensile strength of the 1040 steel (perhaps the result of strain-aging, since no such increase was observed in the yield strength). At the same time, the elongation and reduction of area of the steels increased. The 4340 and Ni-Cr-Mo-V steels retained their strength to approximately the same degree with increasing temperature, but the 1040 steel was significantly weaker than the alloy grades at 850 and 1000 F.

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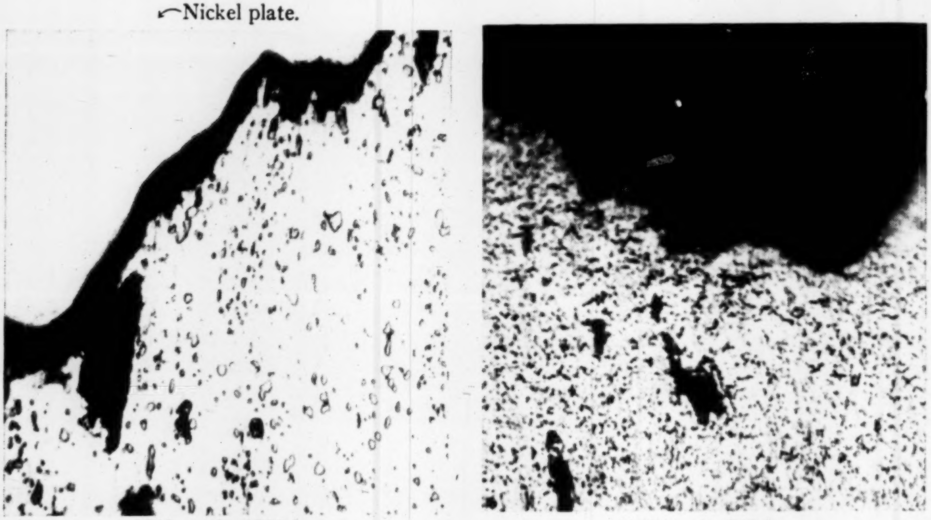
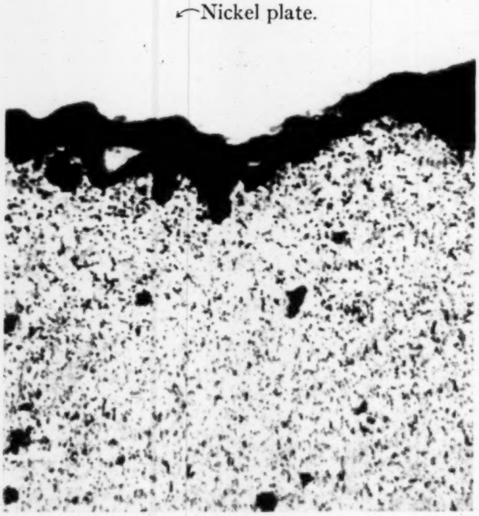
[4] The plots of stress *versus* ratio of elongation at rupture to time at rupture have been found useful for extrapolating ductility to longer rupture times than can be tested, as shown in:

G. V. Smith, "Properties of Metals at Elevated Temperatures," McGraw-Hill Book Co., Inc., New York, N. Y., p. 151 (1950).



1040 steel—1780 hr. 4340 steel—540 hr.



Ni-Cr-Mo-V steel—770 hr.

FIG. 9.—Microstructures at Fracture of Longest-Time Rupture Test Specimen at 1000 F. Etched in picral (× 1000).

In the creep-rupture tests the inferiority of the 1040 steel was even more marked. Of the two alloy grades, the Ni-Cr-Mo-V steel was superior to the 4340 at both 850 and 1000 F, with the superiority more marked at the higher temperature. All three steels showed good ductility in the creep-rupture tests. Carbide spheroidization was more pronounced the higher the test temperature and the longer the test time. Fractures appeared to be transgranular at all temperatures but tended toward intergranular at the longest times at the highest temperature.

Acknowledgment:

We are pleased to acknowledge the assistance of P. R. Wray, J. M. Hodge, and J. J. Heger in formulating the program and obtaining the test steels, and of E. G. Houston, W. L. Jensen, E. J. Dulis, and B. W. Royle in carrying out the work.

THE CREEP CHARACTERISTICS OF COPPER-NICKEL ALLOYS AT 300, 400, AND 500 F*

By J. H. Port[1] and A. I. Blank[2]

Although copper-nickel alloys have been used for many years in applications involving stress at elevated temperatures, as in heat exchangers and unfired pressure vessels, very little information pertaining to the creep properties of these materials has been published. Creep properties of a 70-30 copper-nickel alloy in the form of $\frac{1}{8}$-in. diameter rod annealed to 0.020-mm grain size were determined by Burghoff, Blank, and Maddigan (**1**).[3] Those data are included in this paper in order to compare the creep properties of the 70-30 composition with those of three other copper-nickel alloys.

Materials

The alloys tested in this investigation were 90-10 copper-nickel containing 0.68 per cent iron, 90-10 copper-nickel containing 1.08 per cent iron, and 80-20 copper-nickel containing 0.19 per cent iron. The chemical composition and the physical properties of each material in the form of $\frac{1}{8}$-in. diam rod are given in Table I. Corresponding data for the 70-30 copper-nickel alloy containing 0.03 per cent iron are also included.

The creep tests were made on $\frac{1}{8}$-in. diameter rod drawn to size, mechanically straightened, and cut to length. The annealed materials were given final anneals following the straightening operation. The 90-10 copper-nickel containing 1.08 per cent iron was tested as drawn 21 per cent reduction in area and as annealed to 0.025-mm grain size. All of the other materials were tested in the as-annealed condition.

Procedure

The creep testing equipment and the method used have been described in detail in previous papers (**1** to **4**). The strain in the specimens was measured over a 10 in. gage length by means of dial indicators which have 0.0001-in. scale divisions and a range of total extension of 2.5 per cent. When the total extension exceeded 2.5 per cent, the indicators were reset without interrupting the creep tests. Temperatures within the gage lengths of all the specimens were carefully controlled and maintained well within the limits specified in ASTM Recommended Practice for Conducting Long-Time High-Temperature Tension Tests of Metallic Materials (E 22 – 41).[4]

Tensile properties at room tempera-

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13–18, 1954.

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[2] Research Metallurgist, Research and Development Dept., Chase Brass and Copper Co., Waterbury, Conn.

[3] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 1049.

[4] 1952 Book of ASTM Standards, Part 1, p. 1445.

TABLE I.—COMPOSITIONS AND PROPERTIES OF MATERIALS TESTED.

Material	Analysis by Weight, per cent	Temper	Yield Strength 0.5 per cent Elongation under Load, psi	Tensile Strength, psi	Elongation in 2 in., per cent
90-10 copper-nickel......	89.06 Cu; 10.10 Ni; 0.68 Fe; 0.15 Mn; 0.01 Zn; <0.003 Pb; <0.002 Si; <0.001 Al; <0.001 Sn	Annealed 0.030-mm grain size	13 900	42 900	44.0
90-10 copper-nickel......	88.49 Cu; 10.17 Ni; 1.08 Fe; 0.12 Mn; 0.11 Zn; 0.03 Pb	Annealed 0.025-mm grain size	14 600	45 800	37.5
		Drawn 21 per cent reduction in area	56 000	61 800	15.5
80-20 copper-nickel......	78.50 Cu; 19.95 Ni; 0.76 Zn; 0.60 Mn; 0.19 Fe; <0.02 Pb	Annealed 0.025-mm grain size	16 400	52 500	40.5
70-30 copper-nickel......	69.07 Cu; 30.06 Ni; 0.80 Mn; 0.03 Fe; 0.005 Pb	Annealed 0.020-mm grain size	21 000	59 000	40.0

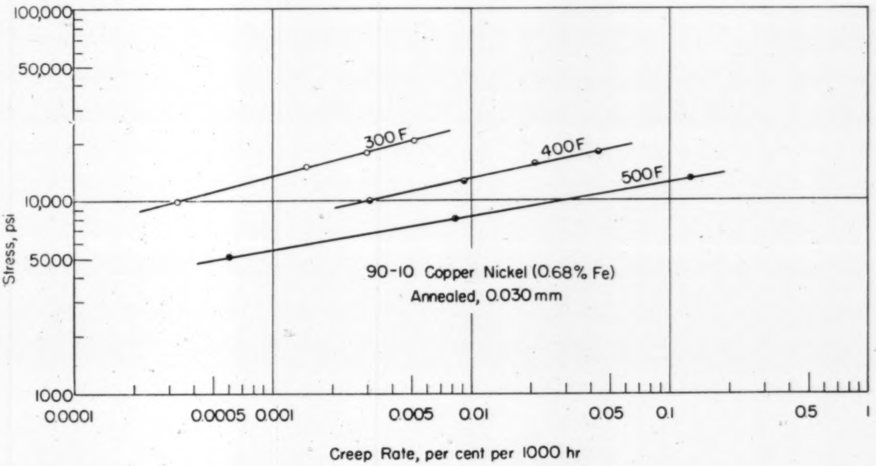

FIG. 1.—Stress and Creep Rate Relationships at 300, 400, and 500 F for Annealed 90-10 Copper-Nickel Alloy Containing 0.68 per cent Iron.

TABLE II.—RESULTS OF CREEP TESTS.

Alloy and Temper	Testing Temperature, deg Fahr	Stress, psi	Total Time, hr	Initial Extension, per cent	Total Creep, per cent	Creep	
						Intercept e_0[a] per cent	Rate, v,[a] per cent per 1000 hr
90-10 copper-nickel (0.68 per cent iron) Annealed 0.030-mm grain size	300	9 850	6070	0.062	0.0369	0.0349	0.0003
		14 950	6070	1.22	0.321	0.3124	0.0015
		17 750	6050	2.10	0.455	0.436	0.0030
		20 400	6050	2.95	0.891	0.859	0.0051
	400	5 850	6070	0.035	0.0224	0.009	0.0022
		10 050	6070	0.103	0.0892	0.071	0.003
		12 600	6070	0.645	0.411	0.354	0.0093
		15 100	6070	1.40	0.514	0.389	0.021
		17 800	6070	2.48	0.915	0.646	0.044
	500	5 050	6200	0.030	0.059	0.0248	0.0006
		8 000	6200	0.050	0.113	0.063	0.0083
		13 050	6200	0.570	1.61	0.819	0.128
90-10 copper-nickel (1.08 per cent iron) Annealed 0.025-mm grain size	300	15 000	6000	0.742	0.1285	0.128	<0.0001
		20 000	6000	1.688	0.443	0.442	0.00016
		25 000	6000	4.54	0.165	0.1637	0.00022
	400	9 200	6000	0.055	0.0035	0.003	0.0001
		14 200	6000	0.520	0.0839	0.0795	0.00073
		19 200	6000	1.964	0.214	0.202	0.002
		22 200	6000	2.592	0.0585	0.042	0.0028
	500	9 200	6000	0.072	0.0180	0.0143	0.00061
		13 150	6000	0.252	0.264	0.2538	0.0017
		18 150	6000	1.604	0.199	0.1756	0.0038
90-10 copper-nickel (1.08 per cent iron) Drawn 21 per cent reduction in area	300	20 050	6000	0.120	0.0191	0.0188	<0.0001
		30 000	6000	0.183	0.016	0.0148	0.0002
		40 050	6000	0.241	0.0362	0.0276	0.00143
		45 000	6000	0.334	0.0755	0.0610	0.0024
		50 000	6000	0.450	0.185	0.164	0.0035
	400	15 150	6000	0.090	0.0204	0.0192	0.0002
		25 150	6000	0.150	0.034	0.028	0.0010
		35 100	6000	0.228	0.0802	0.0628	0.0029
		40 000	6000	0.262	0.1495	0.1115	0.0063
		45 100	6000	0.346	0.363	0.143	0.0366
	500	20 300	6000	0.128	0.0708	0.0576	0.0022
		30 150	6000	0.192	0.2505	0.169	0.0136
		35 500	4320	0.228	0.379	0.189	0.044
		35 500	6000	0.228	0.472	0.102	0.0617[b]
80-20 copper-nickel Annealed 0.025-mm grain size	300	10 000	6200	0.080	0.005	0.0045	0.0001
		15 000	6200	0.145	0.0105	0.010	0.0001
		20 000	6200	1.120	0.106	0.104	0.0004
		24 900	6200	2.380	1.103	1.100	0.0004
	500	10 000	6200	0.100	0.017	0.013	0.0006
		15 000	6200	0.470	0.011	0.008	0.0004
		20 000	6200	1.560	0.125	0.086	0.006
		22 100	6200	1.794	0.380	0.369	0.0012
		25 000	6200	3.110	0.0195	0.0125	0.0011

TABLE II.—*Concluded.*

Alloy and Temper	Testing Temperature, deg Fahr	Stress, psi	Total Time, hr	Initial Extension, per cent	Total Creep, per cent	Creep	
						Intercept e_0[a] per cent	Rate, v,[a] per cent per 1000 hr
70-30 copper-nickel Annealed 0.020-mm grain size	300	4 550	2600	0.023	0.010	0.010	<0.0001
		15 100	2600	0.087	0.022	0.022	<0.0001
		19 900	4400	0.86	0.024	0.022	0.0004
		28 450	5200	3.20	0.030	0.025	0.001
		32 700	3700	4.50	0.032	0.030	0.0006
	400	4 980	2880	0.022	0.004	0.004	0.0001
		15 950	4100	0.160	0.007	0.006	0.0002
	500	4 980	2780	0.030	0.001	0.001	0.0001
		10 250	5000	0.062	0.013	0.013	<0.0005
		15 650	3260	0.29	0.011	0.008	0.0009
		21 150	5000	1.45	0.048	0.030	0.0037
		26 500	3260	2.72	0.045	0.028	0.0054
		30 650	5100	4.58	0.091	0.048	0.0084

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[a] The values e_0 and v may be used in the McVetty type of formula (5) for calculating amount of creep as follows:

$$\text{Creep} = e_0 + vt$$

where:

e_0 = a constant (intercept for zero time on creep-time plot),
v = creep rate (slope or tangent to creep curve), and
t = time

[b] Third stage of creep, accelerating creep rate.

TABLE III.—SUMMARY OF CREEP PROPERTIES.[a]

Material	Temper	Temperature, deg Fahr	Stress, psi for Designated Creep Rate		
			0.001 per cent per 1000 hr	0.01 per cent per 1000 hr	0.1 per cent per 1000 hr
90-10 copper-nickel (0.68 per cent iron)	Annealed 0.030-mm grain size	300	13 500	(24 000)	(>25 000)
		400	(7 500)	12 800	(21 500)
		500	5 600	8 300	12 400
90-10 copper-nickel (1.08 per cent iron)	Annealed 0.025-mm grain size	300	>30 000	...	...
		400	16 000	(30 000)	...
		500	11 000	(24 500)	...
90-10 copper-nickel (1.08 per cent iron)	Drawn 21 per cent reduction in area	300	37 800	>50 000	...
		400	25 600	42 500	(46 000)
		500	16 700	28 500	36 000
80-20 copper-nickel	Annealed 0.025-mm grain size	300	>25 000	...	...
		400	...	...	...
		500	17 000	>30 000	...
70-30 copper-nicke	Annealed 0.020-mm grain size	300	24 000	(35 000)	...
		400	...	...	...
		500	16 000	(30 000)	...

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[a] Values enclosed in parentheses were derived by extrapolation.

ture were determined on the same $\frac{1}{8}$-in. diameter rod using a 50,000-lb Baldwin-Southwark universal testing machine equipped with automatic stress-strain recording equipment. Stress-strain tests at elevated temperatures were made in the creep furnaces by applying incremental loads directly to the specimens and measuring strain with the dial indicators.

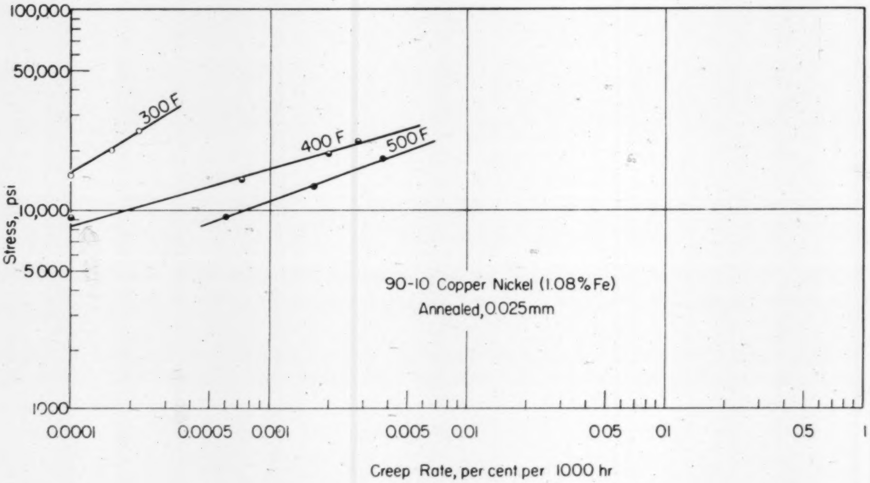

FIG. 2.—Stress and Creep Rate Relationships at 300, 400, and 500 F for Annealed 90-10 Copper-Nickel Alloy Containing 1.08 per cent Iron.

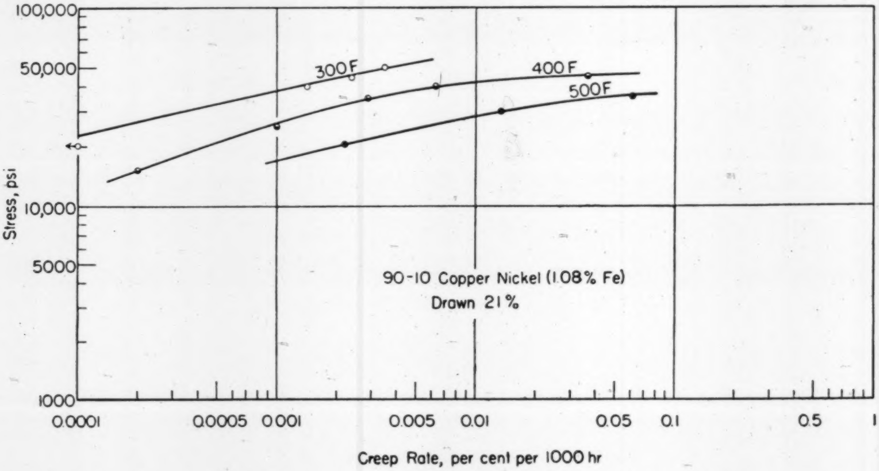

FIG. 3.—Stress and Creep Rate Relationships at 300, 400, and 500 F for Hard-drawn 90-10 Copper-Nickel Alloy Containing 1.08 per cent Iron.

DISCUSSION OF TEST RESULTS

The results of the creep tests, which were run at constant load for 6000 hr in most cases, are listed in Table II.

The indicated creep rates were taken from the extension *versus* time curves at 6000 hr, at which time most of the creep rates were either constant or decreasing very slightly.

The creep properties of the various copper-nickel alloys at 300, 400, and 500 F are summarized in Table III by the stresses which produce creep rates of 0.001, 0.01, and 0.1 per cent per 1000 hr at 6000 hr. These stresses were taken from the log stress *versus* log creep rate curves shown in Figs. 1 to 5.

The values of stress which produced a

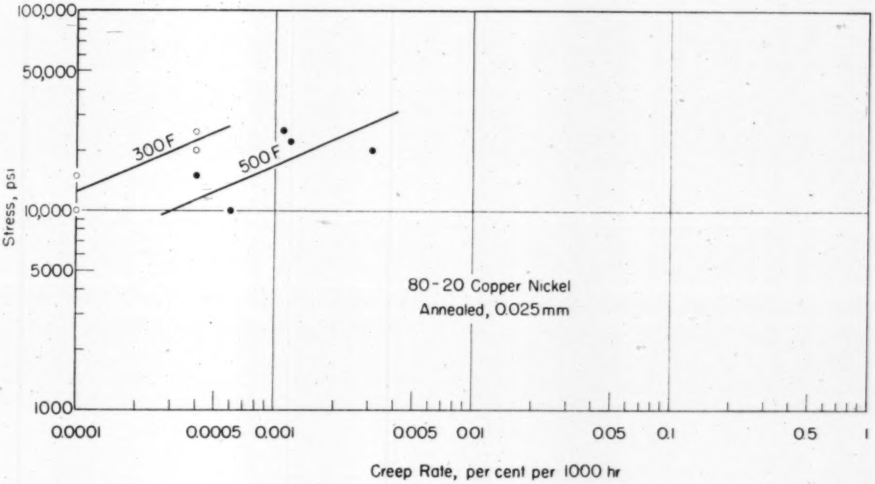

FIG. 4.—Stress and Creep Rate Relationships at 300 and 500 F for Annealed 80-20 Copper-Nickel Alloy Containing 0.19 per cent Iron.

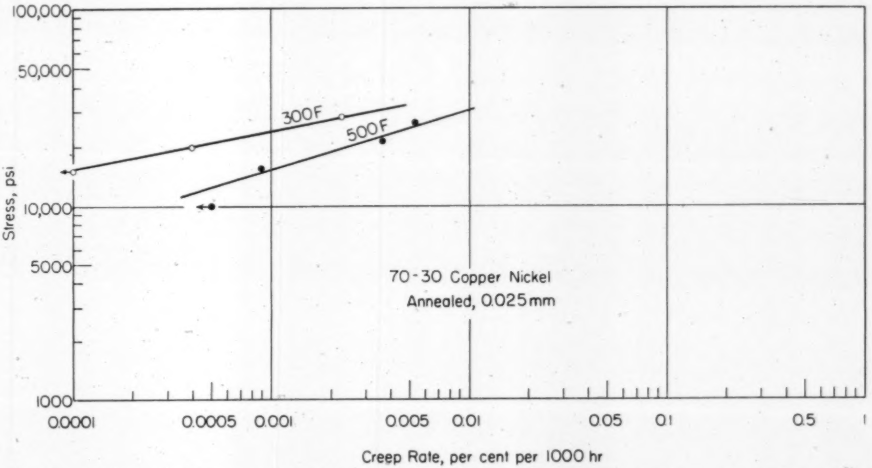

FIG. 5.—Stress and Creep Rate Relationships at 300 and 500 F for Annealed 70-30 Copper-Nickel Alloy Containing 0.03 per cent Iron.

creep rate of 0.001 per cent per 1000 hr were used for comparing the relative creep strengths of these materials. Although the creep rate of 0.01 per cent per 1000 hr is frequently used for such comparison, it was found more convenient in this case to use the value of 0.001 per cent per 1000 hr. The stresses which produced a creep rate of only 0.001 per cent per 1000 hr were well above the yield strengths of the annealed materials and considerable initial extension took place upon application of the load. It will be noted from the data in Table II that the initial extensions of some of the tests made at higher stresses were quite high, as much as 4 per cent or more. Although the annealed materials creep very little, even under moderately high stress, the amount of initial extension which results may be prohibitive. This limitation can be significantly reduced by small amounts of cold work, as will be shown later.

The effect of temperature on creep strength, represented by the stress that produces a creep rate of 0.001 per cent per 1000 hr, is shown in Table III and Fig. 6. The creep strengths of the annealed 90-10 copper-nickel alloys containing 0.68 and 1.08 per cent iron decrease appreciably as the temperature increases from 300 to 500 F. This is also true for the hard-drawn temper of the higher iron-bearing alloy. However, it is apparent from Fig. 6 that although the creep strengths of 80-20 copper-nickel and 70-30 copper-nickel decrease as the temperature increases, they are affected much less by temperature than the 90-10 copper-nickel alloys.

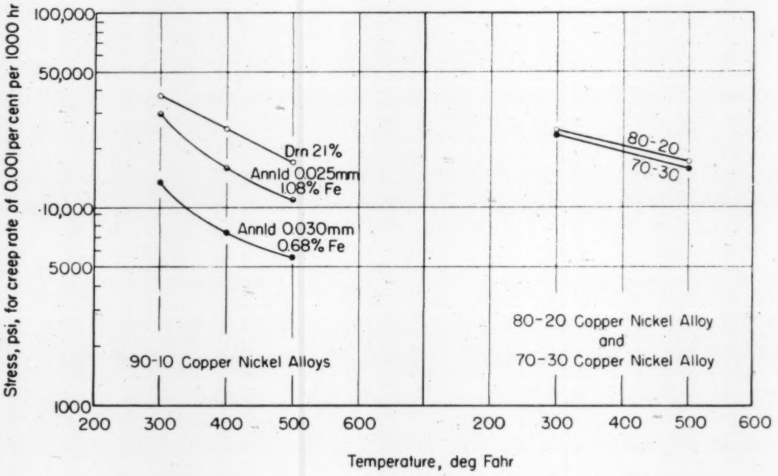

FIG. 6.—Creep Strength and Temperature Relationships for 90-10, 80-20, and 70-30 Copper-Nickel Alloys.

The effects of alloy content and cold working on the creep strengths of these materials at 300, 400, and 500 F are shown in Fig. 7. It is apparent that iron has a very appreciable effect on the creep strength of 90-10 copper-nickel alloy at 300, 400, and 500 F. The 90-10 copper-nickel alloy containing 1.08 per cent iron, annealed to 0.025-mm grain size, has two or more times the creep strength of the alloy with 0.68 per cent iron annealed to 0.030-mm grain size. The slight difference in the grain sizes of these two materials is believed to be insignificant. It is of further interest that at 300 F the annealed 90-10 copper-nickel containing 1.08 per cent iron has greater creep strength than the annealed 80-20 and annealed 70-30 copper-nickel alloys. However, at 500 F, the creep strengths of both 80-20 and 70-30 copper-nickel alloys exceed that of the annealed 90-10 copper-nickel containing 1.08 per cent iron by about 50 per cent. Of all the copper-nickel alloys considered here, the best creep properties are exhibited by the 90-10 copper-nickel alloy containing 1.08 per cent iron as drawn 21 per cent reduction in area. The creep strength of this drawn material is considerably higher than that of the annealed 80-20 and the annealed 70-30 copper-nickel alloys at 300 F, and at 500 F the creep strengths of the three alloys are substantially equal. In addition, for creep rates at 6000 hr produced by stresses above the proportional limits of these materials, the total extension of the drawn 90-10 copper-nickel is very much less than that of the annealed 80-20 and 70-30 copper-nickel alloys because the initial extension is appreciably less for the drawn material.

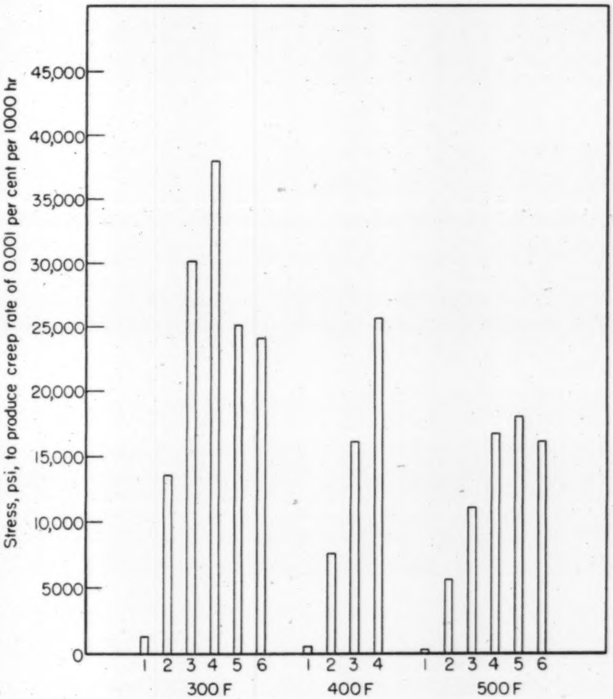

Fig. 7.—Creep Strength of Copper and Copper-Nickel Alloys at 300, 400, and 500 F.

1—Electrolytic tough pitch copper annealed 0.025-mm grain size. 2—90-10 copper-nickel alloy (0.68 per cent iron) annealed 0.030-mm grain size. 3—90-10 copper-nickel alloy (1.08 per cent iron) annealed 0.025-mm grain size. 4—90-10 copper-nickel alloy (1.08 per cent iron) cold drawn 21 per cent reduction in area. 5—80-20 copper-nickel alloy (0.19 per cent iron) annealed 0.025-mm grain size. 6—70-30 copper-nickel alloy (0.03 per cent iron) annealed 0.020-mm grain size.

It is of interest to note the effect of the higher iron content on the annealing

TABLE IV.—EFFECT OF CREEP TEST EXPOSURES ON ROOM TEMPERATURE PROPERTIES.

Material and Temper	Creep Testing			Tensile Strength, psi	Elongation in 2 in. per cent	Microstructure
	Temperature, deg Fahr	Stress, psi	Time, hr			
90-10 copper-nickel (0.68 per cent iron) Annealed 0.030-mm grain size	(As processed)			42 900	44.0	Alpha Grains
	300	9 850	6070	44 000	39.5	Unchanged
		14 950	6070	43 500	40.0	Unchanged
		17 750	6050	44 200	40.0	Unchanged
		20 400	6050	44 000	36.0	Unchanged
	400	10 050	6070	43 800	40.5	Unchanged
		12 600	6070	43 500	39.0	Unchanged
		15 100	6070	43 000	38.5	Unchanged
		17 800	6070	41 700	...	Unchanged
	500	5 050	6200	44 600	40.0	Unchanged
		8 000	6200	43 900	39.0	Unchanged
90-10 copper-nickel (1.08 per cent iron) Annealed 0.025-mm grain size	(As processed)			45 800	37.5	Alpha Grains
	300	15 000	6000	45 000	35.0	Unchanged
		20 000	6000	45 900	35.0	Unchanged
		25 000	6000	45 300	33.5	Unchanged
	400	9 200	6000	46 400	36.0	Unchanged
		14 200	6000	46 600	37.0	Unchanged
		19 200	6000	46 800	37.0	Unchanged
		22 200	6000	45 400	32.0	Unchanged
	500	9 200	6000	46 800	31.5	Unchanged
		13 150	6000	46 200	31.5	Unchanged
		18 150	6000	46 100	...	Unchanged
90-10 copper-nickel (1.08 per cent iron) Drawn 21 per cent reduction in area	(As processed)			61 800	15.5	Slightly worked structure
	300	20 050	6000	62 400	15.5	As Drawn
		30 000	6000	63 000	15.0	As Drawn
		40 050	6000	61 800	15.0	As Drawn
		45 000	6000	62 400	15.5	As Drawn
		50 000	6000	62 400	15.5	As Drawn
	400	15 150	6000	61 400	16.5	As Drawn
		25 150	6000	62 000	16.0	As Drawn
		35 100	6000	62 200	15.0	As Drawn
		40 000	6000	61 000	15.0	As Drawn
		45 100	6000	61 000	11.5	As Drawn
	500	20 300	6800	60 900	14.5	As Drawn
		30 150	6800	61 200	15.0	As Drawn
		35 500	6000	57 700	...	As Drawn
		40 100	1000	57 900	...	As Drawn
80-20 copper-nickel Annealed 0.025-mm grain size	(As processed)			52 500	40.5	Alpha Grains
	500	15 000	6200	53 600	35.0	Unchanged
		22 100	6200	53 700	31.5	Unchanged
70-30 copper-nickel Annealed 0.020-mm grain size	(As processed)			59 000	40.0	Alpha Grains
	500	4 980	2780	59 500	38.0	Unchanged

characteristics of the 90-10 copper-nickel alloy. In processing these materials it was noted that the 1.08 per cent iron had a considerable effect as a grain size inhibitor. Following a reduction in area of 81.5 per cent from a penultimate grain size of 0.035 mm the 90-10 copper-nickel containing 0.68 per cent iron was annealed at 1200 F to produce a final grain size of 0.030 mm. On the other hand, the alloy containing 1.08 per cent iron having been drawn 78.5 per cent reduction in area after a penultimate anneal to an 0.030-mm grain size, was annealed at 1360 F to produce a final grain size of 0.025 mm. Although the penultimate grain sizes and final reductions were substantially the same, the alloy of higher iron content required an annealing exposure at a higher temperature to produce the final grain size. Prior to the penultimate anneals these materials were annealed in production furnaces at 1300 to 1400 F.

The materials used for these creep tests were given careful microscopic examination before and after testing. As shown in Table IV the structures of these materials were stable at 300, 400, and 500 F. No indications of recrystallization and softening were seen in the 90-10 copper-nickel alloy drawn 21 per cent. Furthermore, no precipitate of free iron could be optically resolved in these materials. The technique used by Palmer and Wilson (6) involving the use of a colloidal suspension of magnetite to detect optically unresolved precipitates of free iron in a copper-nickel alloy was successfully employed. The micrographs of Fig. 8 show the presence of free iron in the annealed 90-10 copper-nickel alloy containing 1.08 per cent iron after exposure in a creep test for 6000 hr at 500 F. This effect was seen in the as-processed material, both as annealed and as drawn 21 per cent. The same technique did not show the presence of any free

(a) Without applied magnetic field—free iron not evident. **(b) With applied magnetic field—free iron evident.**

FIG. 8.—90-10 Copper-Nickel Alloy (1.08 per cent Iron) Annealed 0.025-mm Grain Size. Exposed for 6000 hr in Creep Test at 500 F (× 500).

Unetched, coated with colloidal suspension of magnetite.

iron in the lower iron-bearing 90-10 copper-nickel alloy either as processed or after testing. These results are in agreement with those of Palmer and Wilson (6) who found that 0.75 per cent iron could be retained in solution in 90-10 copper-nickel alloy using normal mill practices and that by taking special precautions, that is, water quenching from the annealing temperature, as much as 1.25 per cent iron could be retained in solution.

The effect of iron in solid solution on creep strength was not determined in this investigation. It is unlikely that the amounts of iron in solid solution were greatly different in the alloys containing 0.68 per cent and 1.08 per cent iron. One might expect, therefore, that the effect of dissolved iron on creep strength would be substantially the same for both alloys. Consequently the marked differences in their creep strengths should probably be attributed largely to the free iron present in the material of higher iron content. The free iron particles observed in this material were disposed mainly along lines substantially parallel to the axis of the rod. The higher creep strength is probably derived from the presence of this free iron in the form of very finely divided particles.

SUMMARY

The creep characteristics of several copper-nickel alloys were determined at 300, 400, and 500 F. At these temperatures the creep strength of annealed 90-10 copper-nickel alloy containing 1.08 per cent iron was two or more times that of 90-10 copper-nickel alloy containing only 0.68 per cent iron. Free iron was observed in the 90-10 copper-nickel containing 1.08 per cent iron, whereas no free iron was detected in the lower iron-bearing 90-10 copper-nickel alloy. In the annealed condition there was no significant difference between the creep strengths at 300 F of 90-10 copper-nickel alloy containing 1.08 per cent iron, 80-20 copper-nickel alloy containing 0.19 per cent iron, and 70-30 copper-nickel alloy containing 0.03 per cent iron. At 500 F the creep strengths of the 80-20 and the 70-30 copper-nickel alloys were very similar, but both were considerably higher than that of the annealed 90-10 copper-nickel alloy containing 1.08 per cent iron.

The creep strength of the 90-10 copper-nickel alloy containing 1.08 per cent iron was considerably improved by cold drawing 21 per cent reduction in area. At 300 F the creep strength of this cold-worked material was greater than that of all the annealed materials, and at 500 F it was about the same as that of the annealed 70-30 and 80-20 copper-nickel alloys. For creep rates produced by stresses above the proportional limits of these materials the total extension of the hard-drawn 90-10 copper-nickel is very much less than that of the annealed materials because the initial extension is significantly less for the drawn material.

Acknowledgments:

The authors acknowledge the interest and guidance of D. K. Crampton and H. L. Burghoff, under whose direction this creep testing program was conducted and the assistance of H. Hughson and other members of the Research and Development Department of the Chase Brass and Copper Co.

REFERENCES

(1) H. L. Burghoff, A. I. Blank, and S. E. Maddigan, "The Creep Characteristics of Some Copper Alloys at Elevated Temperatures," *Proceedings*, Am. Soc. Testing Mats., Vol. 42, p. 668 (1942).

(2) H. L. Burghoff and A. I. Blank, "Creep Characteristics of a Phosphorized Copper," *Transactions*, Am. Inst. Mining and Metallurgical Engrs., Vol. 161, p. 420 (1945).

(3) H. L. Burghoff and A. I. Blank, "The Creep Characteristics of Copper and Some Copper Alloys at 300, 400, and 500 F," *Proceedings*, Am. Soc. Testing Mats., Vol. 47, p. 725 (1947).

(4) A. I. Blank and H. L. Burghoff, "Creep Characteristics of Phosphorized Copper (0.019 per cent P) at 300, 400, and 500 F," *Proceedings*, Am. Soc. Testing Mats., Vol. 51, p. 981 (1951).

(5) P. G. McVetty, "The Interpretation of Creep Tests," *Proceedings*, Am. Soc. Testing Mats., Vol. 34, Part II, p. 105 (1934).

(6) E. W. Palmer and F. H. Wilson, "Constitution and Properties of Some Iron-Bearing Cupro-Nickels." *Transactions*, Am. Inst. Mining and Metallurgical Engrs., Vol. 194, p. 55 (1952).

CREEP PROPERTIES OF ANNEALED UNALLOYED ZIRCONIUM*

By M. J. Manjoine[1] and W. L. Mudge, Jr.[1]

Synopsis

The creep properties of unalloyed zirconium depend on the state of anneal. Up to 600 F (315 C) the plastic flow on loading is so much larger than the creep strain for 1000 hr that creep can be neglected in design for such service lives. Above 600 F creep plays an increasingly important rôle and must be taken into account.

The strain of unalloyed zirconium can be expressed as a function of stress, strain, and time as follows:

$$\epsilon = \epsilon_0 + \dot{\epsilon}t = Ae^{-(B/T)}\,\sigma^{m} + \left[C_1e^{-C_2/T}\sinh\frac{\bar{\sigma}^2}{C_3T}\right]t$$

where ϵ is the strain, $\dot{\epsilon}$ is the strain rate, σ is the stress, $\bar{\sigma}$ is the true stress at the intercept strain (ϵ_0), T is the absolute temperature, t is the time, and the other quantities are constants. Therefore, the strain of unalloyed zirconium follows the McVetty analysis, and the creep rate conforms to the hyperbolic sine law suggested by Nadai with the temperature-dependent coefficient following the reaction rate theory as described by Kauzmann.

The physical reasoning for the hyperbolic sine law and the influence of stress on the energy term of the reaction rate coefficient are discussed.

Studies of the kinetics of the annealing process of cold-rolled zirconium (**1**, **2**)[2] have shown that the characteristics of the annealing behavior of zirconium differ markedly from those of many other metals; that is, the major changes in hardness, annealing texture, and electrical resistivity take place long after recrystallization is apparently complete (as evaluated by metallographic examination of the microstructure). Such studies as are available on the creep behavior of zirconium have neglected the importance of proper annealing (**3**, **4**).

Presented below is a determination of the creep properties of unalloyed zirconium at 500, 600, and 750 F (260, 315, and 400 C); also reported are data which show the dependency of creep properties on the state of anneal of the material.

Experimental Procedure

Material:

The unalloyed zirconium used in these tests was obtained from two double arc-melted ingots of iodide crystal bar (ingots Nos. F129 and F544). The

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13–18, 1954.

[1] Research Laboratories and Atomic Power Division, respectively, Westinghouse Electric Corp., Pittsburgh, Pa.

[2] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 1066.

TABLE 1.—CHEMICAL COMPOSITION OF UNALLOYED ZIRCONIUM, WEIGHT PER CENT.

	F129	F544
Spectrographic:		
Aluminum	0.003	0.004
Chromium	0.002	0.005
Copper	0.0005[a]	0.0005[a]
Iron	0.02	0.05
Hafnium	0.04	0.04
Molybdenum	0.001	0.001[a]
Nickel	0.002	0.005
Silicon	0.005	0.003
Tin	0.001	0.001
Titanium	0.002	0.001
Chemical:		
Carbon	0.02	0.01
Nitrogen	0.001	0.001
Oxygen	[b]	0.023
Hydrogen	[b]	34 ppm

[a] Less than.
[b] Not determined.

analyses of these materials are listed in Table I.

Specimen Preparation:

The sheet stock used for the specimens was hot forged and rolled at 1400 F (760 C) from 4-in. arc-melted ingots and then cold rolled 10 per cent to 0.06 in. Specimen blanks were milled to 0.040 in. by removal of equal amounts of material from both sides. Sheet specimens having the nominal dimensions shown in Fig. 1 were machined after the end tabs were spot welded to the milled specimen blanks. Axial alignment was obtained by machining the specimen gage length with reference to the loading holes, the specimen being free to rotate about the pins in these holes during testing.

A specimen design of this type has the following advantages: The cross-sectional area of the shoulders is considerably increased by the spot-welded tabs so that a small diameter pin can be used to connect the specimen to the extension piece. This results in a smaller specimen shoulder and a much smaller extension piece for a relatively large specimen width. Thus larger width specimen gage lengths can be used in standard creep furnaces with simple extension pieces.

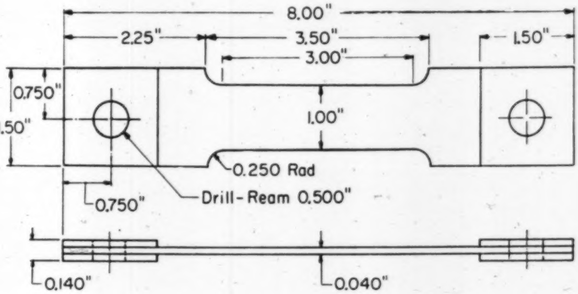

FIG. 1.—Tensile Creep Specimen.

Equipment:

Creep tests were run in spring-loaded autographic creep-rupture machines (5) and lever-arm machines. The latter machines, Fig. 2, have a 5 to 1 lever arm which is counterbalanced to permit the application of very low loads. The extensometer used in the lever-arm machines is shown to the right in Fig. 3. Since the specimen shoulders and grips are small, an extensometer for round specimens (5) was adapted for flat specimens. The details of the extensometer clamps can be seen to the left in Fig. 3. The effect of bending is minimized by the gimbal action of the two-piece clamp. The clamps can be attached either to the gage length or to the shoulders. In the tests reported below the extensometer was attached to the shoulders, since many of the specimens were carried to rupture. An effective gage length was determined to calculate the strains.

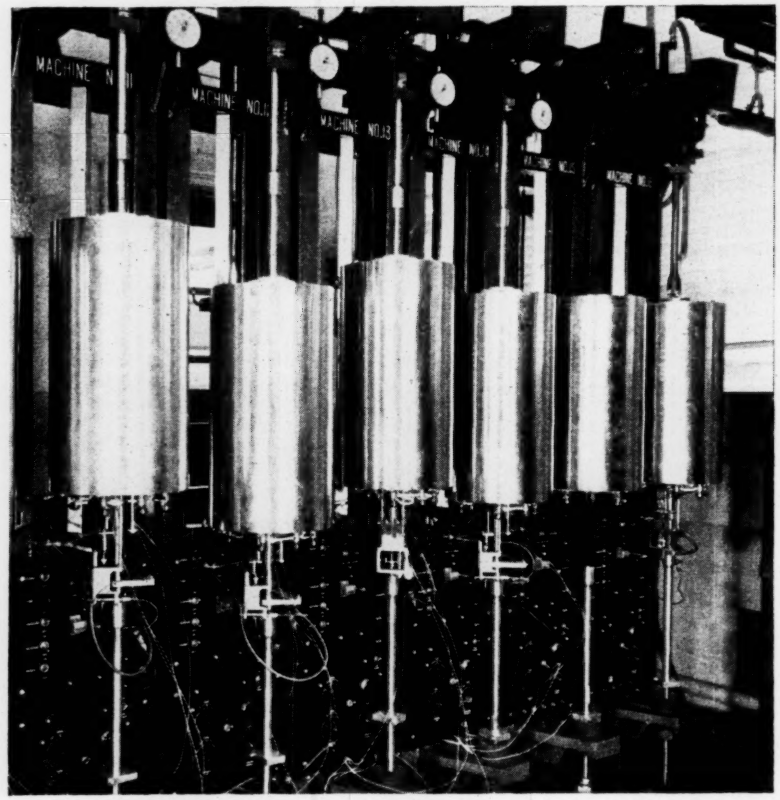

FIG. 2.—Lever-Arm Creep Machines, 5 to 1 Lever Ratio.

TEST RESULTS

Effect of State of Anneal on Creep of Zirconium at 500 F:

The creep properties in this section are reported for three levels of annealing as evaluated quantitatively by their resultant hardness. Measurement of hardness has been shown to be an effective measure of the state of anneal of zirconium (1). The three annealing treatments used are described below:

Anneal No. 1.—Specimens from ingot F129 were annealed at 1110 F (600 C) for $\frac{1}{2}$ hr in a vacuum of less than 0.03μ followed by a furnace cool. Comparison of the results of the three annealing treatments used showed that these specimens had the highest hardness, 92.5 ± 2.5 diamond pyramid hardness (DPH), and a grain size of 0.019 mm diameter (ASTM Nos. 8–9).

Anneal No. 2.—Certain specimens from ingot F544 were slowly heated to

1290 F (700 C), held for 1 hr in vacuum as above, and then furnace cooled. The resulting hardness was lower, 88 ± 4.6 DPH, and the grain size was larger, 0.05 mm diameter (ASTM No. 6).

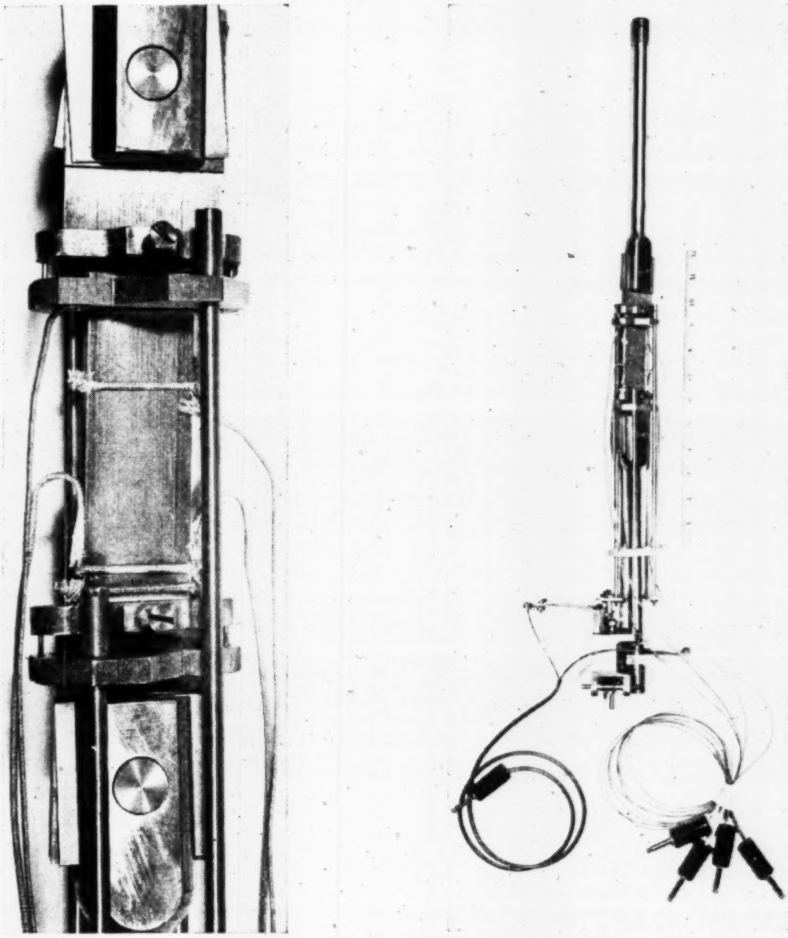

FIG. 3.—High-Temperature Creep Extensometer.

Anneal No. 3.—Subsequent to the work of McGeary and Lustman (1) other specimens of ingot F544 were annealed for 20 hr in vacuum at 1380 F (750 C). The resulting specimens had a hardness of 73 ± 1.7 DPH and a grain size of 0.05 mm diameter (ASTM No. 6). This is the same grain size as that obtained in anneal No. 2.

Anneal No. 1 is the anneal given the material reported in reference (3) and is similar to that reported in reference (4). The creep data of reference (4) are similar to those in reference (3).

The steady state creep rates at 500 F (260 C) of unalloyed zirconium specimens with anneals Nos. 1 and 2 are listed in Table II. The creep data for the "fully annealed" specimens, anneal No. 3, are listed in Table III. For a comparison of the effects of these anneals, the minimum creep rate data for 500 F (260 C) are plotted in Fig. 4. The upper curve for specimens with the highest hardness, anneal No. 1, shows a uniform change in creep rate with change in stress which is closely approximated by a straight line on the semilogarithmic plot. An increase in stress of 2000 psi is required to increase the creep rate by a factor of 10. The cross-hatched region covers the range of data obtained from specimens given anneal No. 2. For fully annealed material, anneal No. 3, an increase in stress of approximately 70 psi will increase the creep rate by a factor of 10. The creep strength for a rate of 10^{-5} per hr increases in the same order as that of the hardness which results from the various annealing treatments as shown in Table IV. Thus, it is important to anneal zirconium in order to obtain reproducible and meaningful creep data. The remainder of the experiments described were performed on specimens of ingot F544 fully annealed, anneal No. 3.

TABLE II.—MINIMUM CREEP RATE OF UNALLOYED ZIRCONIUM AT 500 F (260 C).

	Stress, psi	Creep Rate per hr	Grain Size, mm	Hardness, DPH
Anneal No. 1—1110 F (600 C)—½ hr—Furnace Cooled				
F129—34L	11 000	5.8×10^{-7}	0.018	89
16L	13 000	6.4×10^{-6}	0.019	93
	16 000	4.3×10^{-4}		
22L	14 000	1.5×10^{-5}	0.017	90
	16 000	1.8×10^{-4}		
41L	17 000	4.7×10^{-4}	0.017	90
Anneal No. 2—1290 F (700 C)—1 hr—Furnace Cooled[b]				
F544—24	10 000	2.5×10^{-7}	0.06	84
12	12 800	2.8×10^{-3}	0.05	83
15	13 900	2.24×10^{-1}	0.06	83
18	14 000	3.5×10^{-6}	0.05	87
5	14 000	3.7×10^{-5}	0.045	86
1	15 600	9.8×10^{-2}	0.045	88
3[a]	17 100	1	[c]	92

[a] Short-time tension test.

[b] The wide variation in creep rates at nearly the same stress (14,000 psi) is a consequence of the states of anneal resulting from different rates of heating to 1290 F.

[c] Not determined.

Creep Properties of "Fully-Annealed" Zirconium at 500, 600, and 750 F (260, 315, and 400 C):

Typical creep curves for zirconium are given in Figs. 5, 6, and 7. At 500 F (260 C) and a stress of 11,000 psi, Fig. 5, the plastic strain on loading is 9.13 per cent. The first stage creep is small in comparison to the loading strain. This test was terminated in the second stage after 4401 hr. At 600 F (315 C) and a stress of 8000 psi, Fig. 6, the plastic strain on loading is 2 per cent and the creep curve is similar to that at 500 F. This test was stopped in the second stage after 4000 hr. At 750 F (400 C) and a stress of 6000 psi, Fig. 7, the strain on loading is 0.46 per cent. The first stage creep is now larger in comparison to the loading strain and all three stages of creep are evident. The test was stopped in the third stage of creep at 1697 hr at which time the strain was over 32 per cent.

The data for all the tests are given in Table III. The recorded plastic strains include the plastic strain which occurred on loading. The strain-intercept, ϵ_0, is the intercept on the strain axis at zero time of a tangent to the creep curve at the minimum creep rate. The rate of creep, $\dot{\epsilon}$, is given in inches per inch per hour or, more simply, per hour. The strain and time at the transition point[3] and at rupture are tabulated. Hardness

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[3] Transition from second and third stages of creep where creep rate has increased 10 per cent over the minimum rate.

TABLE III.—CREEP OF ZIRCONIUM (F544) ANNEALED AT 1380 F (750 C) FOR 20 HR AND FURNACE COOLED (ANNEAL NO. 3).

Specimen	Stress, psi		Strain Intercept ϵ_0, per cent	Creep Rate, $\dot{\epsilon}$, per hr	Transition Point		Rupture		Reduction of Area, per cent	Hardness, DPH
	Nominal[a] σ	"True"[b] $\bar{\sigma}$			Time, hr	Strain, per cent	Time, hr	Strain, per cent		
				500 F						
No. 36....	8 500	8 710	2.5	10^{-8}	2124[g]	2.50[d, g]	...	...	...	76
No. 28....	10 000	10 820	8.16	1.8×10^{-7}	3950[g]	8.23[d, g]	...	...	...	72.5
No. 44....	10 750	12 300	14.5	4×10^{-7}	3662[g]	15.0[e, g]	...	...	...	72.5
No. 60....	11 000	12 200	10.6	4.1×10^{-7}	4401[g]	10.78[d, g]	...	...	...	74
No. 33....	11 000	12 100	10.06	3×10^{-6}	...	...	...	...	...	76
No. 33....	11 000[c]	...	...	4.2×10^{-6}	4146[g]	11.47[d, g]	...	...	...	76
No. 27....	11 250	14 350	24.6	4.05×10^{-3}	18.8	32.4	24.1	46.6	53.6	72
No. 37....	11 500	14 800	26.6	6.3×10^{-4}	60	30.6	85	39.0	42.5	71
No. 29....	12 000	15 300	24.25	2.2×10^{-2}	2.1	29.3	6	51.5	29.4	75
No. 31....	13 120	16 300	24.4	2.1×10^{-1}	0.33	34.4	1	55.2	53.7	76
No. 26....	14 000[f]	18 100	...	1	...	...	...	...	...	...
				600 F						
No. 48....	8 000	8 180	2.20	5.6×10^{-7}	4000[g]	2.43[d]	...	...	...	73
No. 45....	9 070	9 820	8.23	6.3×10^{-7}	3800[g]	8.47	5181[g]	8.9[d, g]	...	70
No. 62....	10 000	11 270	12.73	1.1×10^{-5}	1100	6.4	2655[g]	15.85[e, g]	...	73.5
No. 61....	10 500	13 040	23.5	1.9×10^{-4}	81	25.2	99	36.6	48.2	74
No. 46....	11 040	14 450	27.0	9.3×10^{-2}	0.7	33.1	1.66	54.6	57.3	72
No. 34....	12 500[f]	15 800	...	1	...	...	...	...	...	75.5
				750 F						
No. 70....	4 000	4 060	1.04	4.1×10^{-6}	1817[g]	1.76[e]	...	...	...	74
No. 47....	6 000	6 690	3.3	1.4×10^{-4}	1060	19.6	1697[g]	32.5[d, g]	...	75
No. 30....	7 500	8 080	4.35	3.45×10^{-4}	445	18.8	937	67.1	61	73
No. 58....	8 750	10 050	6.0	6.05×10^{-3}	16	15.3	46	47.8	36.6	73
No. 49, 52..	11 040[f]	13 000	...	1	...	...	...	...	...	72

[a] Load per original area.

[b] $\bar{\sigma} \cong \sigma(1 + \epsilon_0)$.

[c] Test moved from spring-loaded to lever-arm creep machine at 1200 hr.

[d] Test stopped.

[e] In progress.

[f] Short time tension test.

[g] Test interrupted or disturbed.

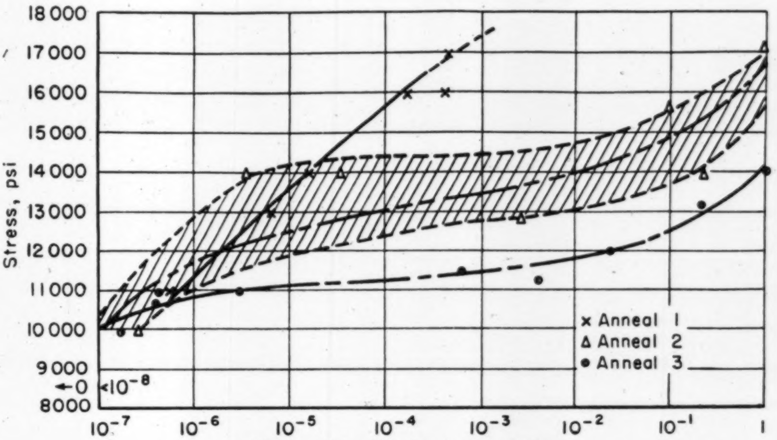

FIG. 4.—Nominal Stress *versus* Minimum Creep Rate of Zirconium at 500 F.

TABLE IV.—CREEP STRENGTH OF UNALLOYED ZIRCONIUM AT 500 F (260 C) AND A CREEP RATE OF 10^{-5} PER HR.

Material	Hardness, DPH	Creep Strength, psi
F129 (Anneal No. 1).......	92.5 ± 2.5	13 500 ± 200
F544 (Anneal No. 2)......	88 ± 4.6	12 000 to 14 000
F544 (Anneal No. 3)......	73 ± 1.7	11 000 ± 200

measurements were made with a Vickers machine using a 20-kg load applied for 15 sec.

The log of the minimum creep rates *versus* the nominal stress, σ, (load divided by original area), at 500, 600, and 750 F (260, 315, and 400 C) are plotted in Fig. 8. These curves are not linear, having lower slopes at intermediate stresses than at either low or high stresses. The stress at the maximum load of a tension test for a head rate giving a strain rate of 1 per hour is included in Fig. 8 for each curve.

Because of the large plastic strain on loading, the creep test starts at a much higher stress than that calculated from the original cross-sectional area. Therefore, in determining the relation between stress and creep rate, it is necessary to correct for the initial extension. When the true stress[4] is used, the curves of Fig. 8 have a different form as shown in Fig. 9. Here the slope of the true stress curve decreases slightly with increasing creep rate over the range investigated.

To illustrate the magnitude of the creep strain relative to the loading strain, the nominal stress is plotted as a

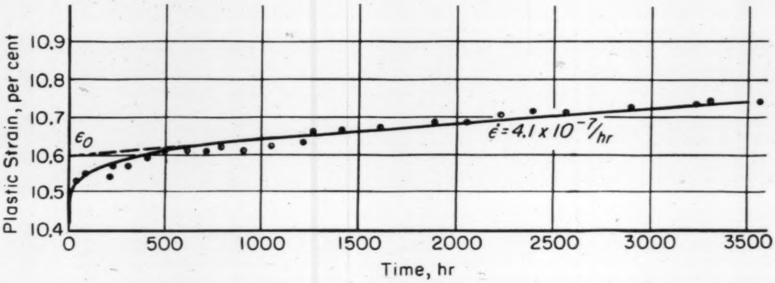

FIG. 5.—Creep Curve for F544 - 60, Temperature 500 F, Stress 11,000 psi.

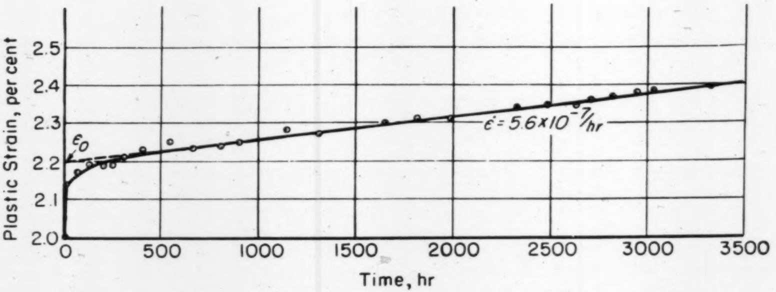

FIG. 6.—Creep Curve for F544 - 48, Temperature 600 F, Stress 8000 psi.

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[4] The true stress used in this report will be defined as $\bar{\sigma} = \sigma\ (1 + \epsilon_0)$ since the intercept strain, ϵ_0 is nearly equal to the strain at the beginning of the second stage or minimum creep ater for temperatures below 750 F (400 C).

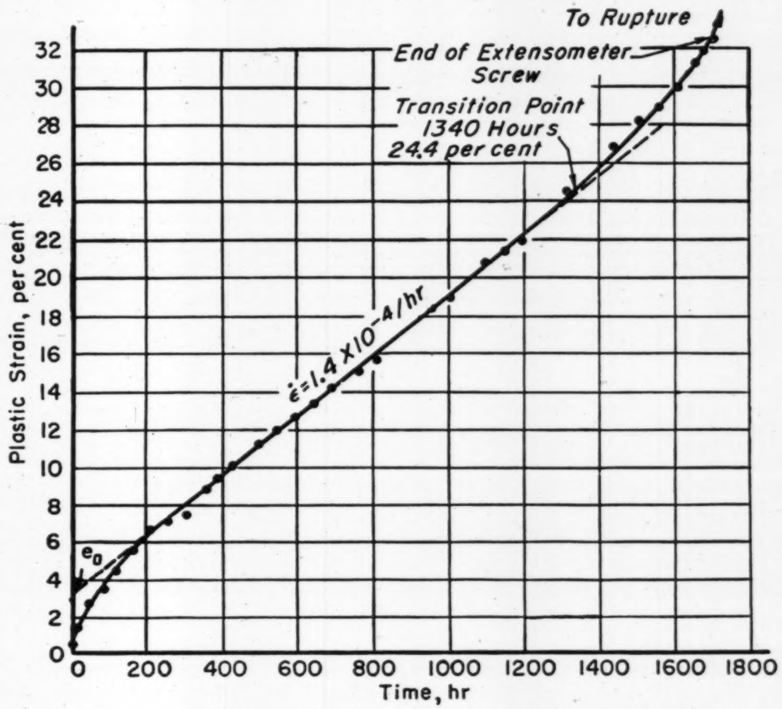

FIG. 7.—Creep Curve for F544 - 47, Temperature 750 F, Stress 6000 psi.

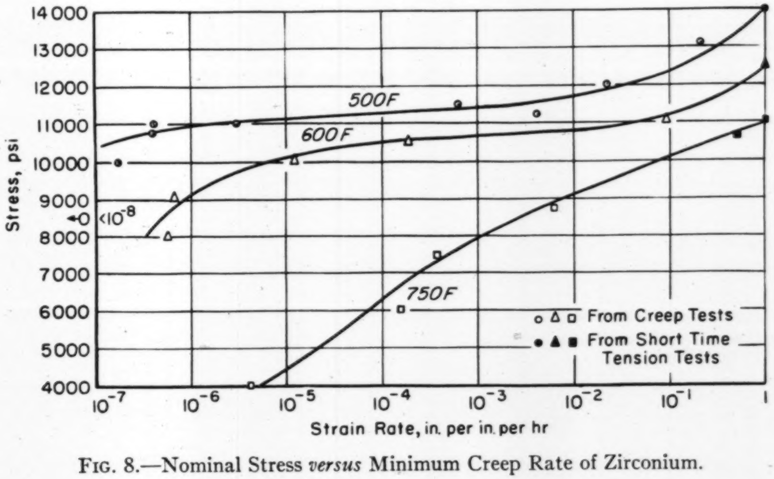

FIG. 8.—Nominal Stress *versus* Minimum Creep Rate of Zirconium.

function of the strain for a given time in Figs. 10, 11, and 12 for 500, 600, 750 F (260, 315, and 400 C) respectively. The times chosen are zero (loading curve) and 1000 hr. At 750 F (400 C) a curve for 100 hr is also included. At 500 or 600 F the plastic strain on loading is so large compared to the creep strain that the loading curve or short-time tensile stress-strain curve can be used for at least 1000-hr design at the lower stresses. However, at 750 F (400 C), Fig. 12, creep plays a major rôle and the creep strength must be considered in any machine design.

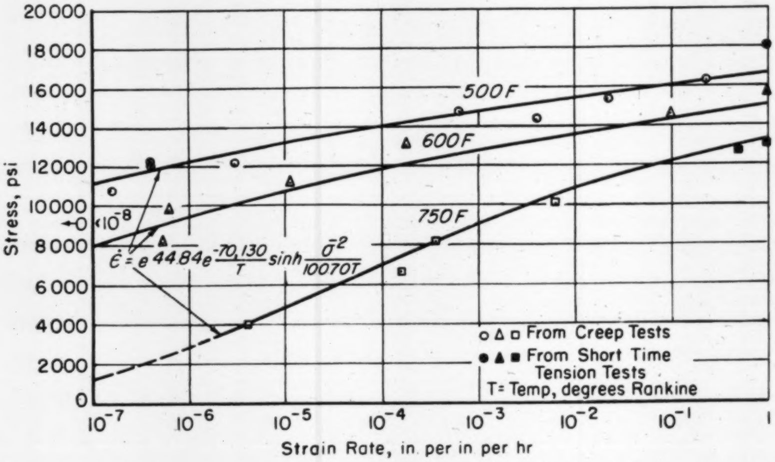

FIG. 9.—True Stress *versus* Minimum Creep Rate of Zirconium.

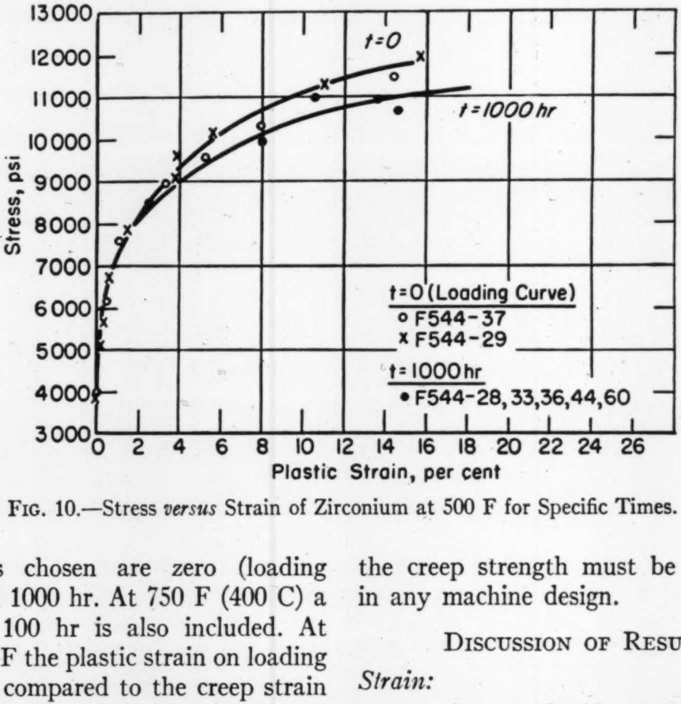

FIG. 10.—Stress *versus* Strain of Zirconium at 500 F for Specific Times.

DISCUSSION OF RESULTS

Strain:

According to McVetty (6) a general expression for the strain, ϵ, up to the transition point is given by

$$\epsilon = \epsilon_0 + \dot{\epsilon}t \qquad (1)$$

where the intercept strain, ϵ_0, is the strain on loading combined with the strain in the first stage of creep and evaluated as the intercept on the strain axis at zero time of a creep curve. The strain resulting from the second stage of creep is expressed by the product of the minimum creep rate, $\dot{\epsilon}$, and the time, t, at constant load (see Figs. 5, 6, and 7).

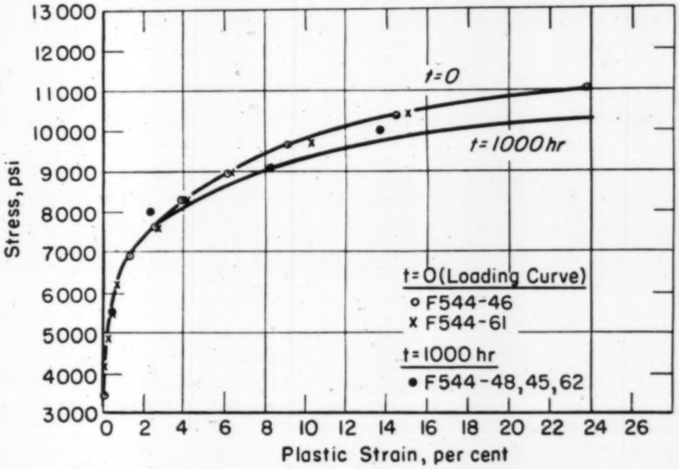

Fig. 11.—Stress *versus* Strain of Zirconium at 600 F for Specific Times.

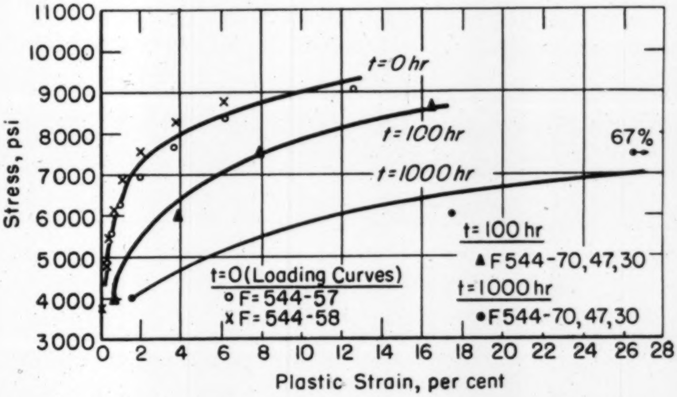

Fig. 12.—Stress *versus* Strain of Zirconium at 750 F for Specific Times.

The relation between the nominal stress, σ, and the strain intercept, ϵ_0, at 500, 600, and 750 F (260, 315, and 400 C) is shown in Fig. 13. The log of the stress is plotted as a function of the log of the intercept strain. At low stresses and temperatures, the first stage creep is small in comparison to the strain on loading so that the loading strain can be used to extrapolate the curve (see Figs. 10 and 11). In Fig. 13 it can be seen that at 500 or 600 F (260 or 315 C) the curve is a straight line through both the intercept and loading strains. At 750 F (400 C), however, the intercept strain at lower stresses is much larger than the loading strain and the points lie to the right of the straight line. Thus, at low stress and high temperature the loading strain cannot be used in place of the intercept strain.

Creep Strength:

The creep strength is the nominal stress for a given rate of flow. This strength as a function of the temperature is plotted in Fig. 14 for three rates of strain: 10^{-2}, 10^{-4}, and 10^{-6} per hr. The tensile strength (strain rate about 1 per hr) is given for comparison. The creep strength of zirconium drops almost linearly with temperature in this range, up to at least 600 F (315 C). At some temperature between 600 and 750 F the strength begins to drop more rapidly at the lower strain rates. The creep strength at a rate of 10^{-6} per hr is frequently taken as a design criterion in high-temperature work. The creep strength expressed in terms of true stress, Fig. 15, produces somewhat similar curves.

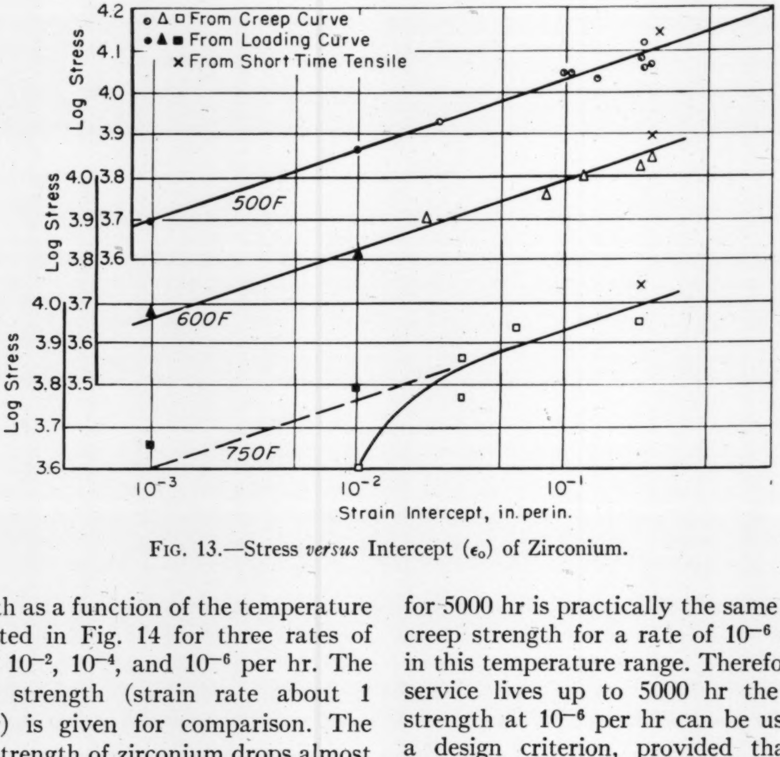

FIG. 13.—Stress *versus* Intercept (ϵ_0) of Zirconium.

Rupture Strength:

For many materials the rupture strength is used as a criterion for high-temperature strength. The rupture strength curves for 100, 1000, and 5000 hr as a function of temperature, Fig. 16, are very similar to the creep strength curves, Fig. 14. The rupture strength for 5000 hr is practically the same as the creep strength for a rate of 10^{-6} per hr in this temperature range. Therefore, for service lives up to 5000 hr the creep strength at 10^{-6} per hr can be used for a design criterion, provided that the resulting strain (Eq 1) is allowable.

ANALYSIS OF RESULTS

Equation 1 is evaluated term by term in the following discussion.

Intercept Strain:

In Fig. 13 the intercept strain, ϵ_0, is shown to be a function of the stress, σ,

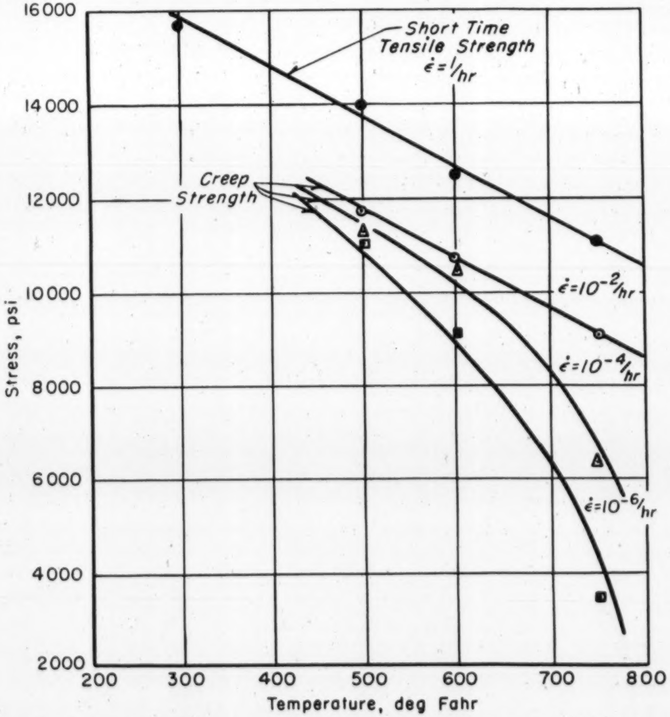

FIG. 14.—Creep Strength of Zirconium *versus* Temperature, for Given Strain Rates.

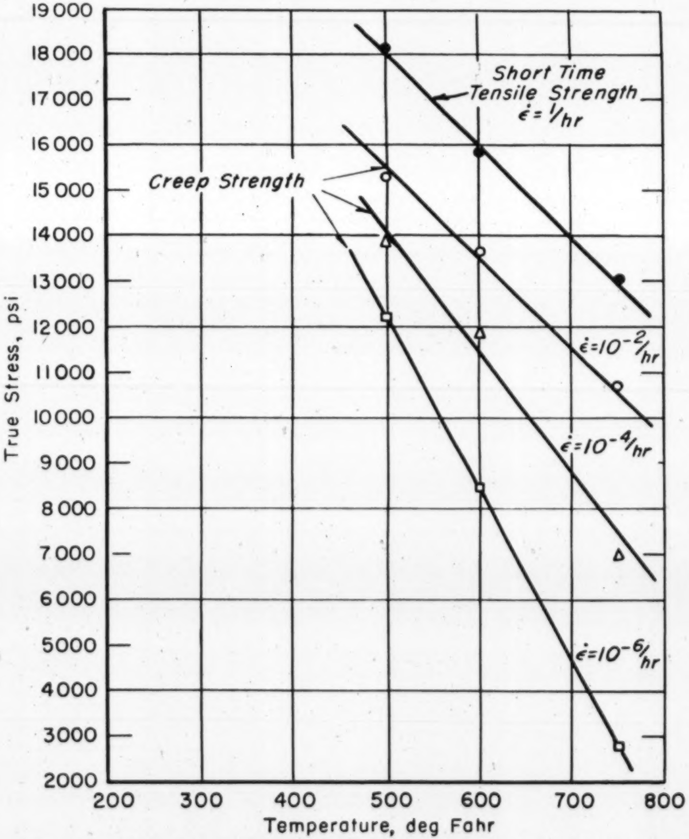

FIG. 15.—True Stress Creep Strength of Zirconium for Given Strain Rates.

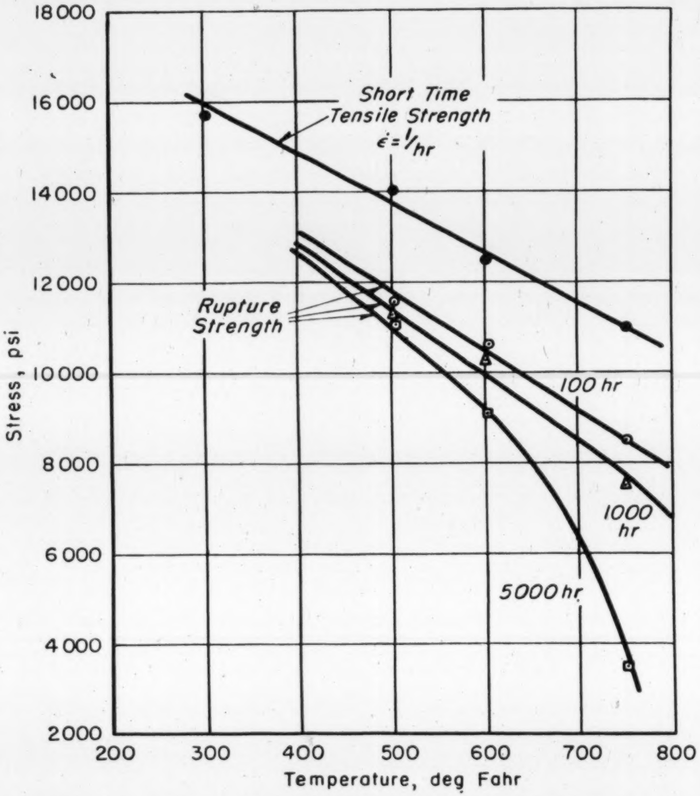

FIG. 16.—Rupture Strength of Zirconium *versus* Temperature.

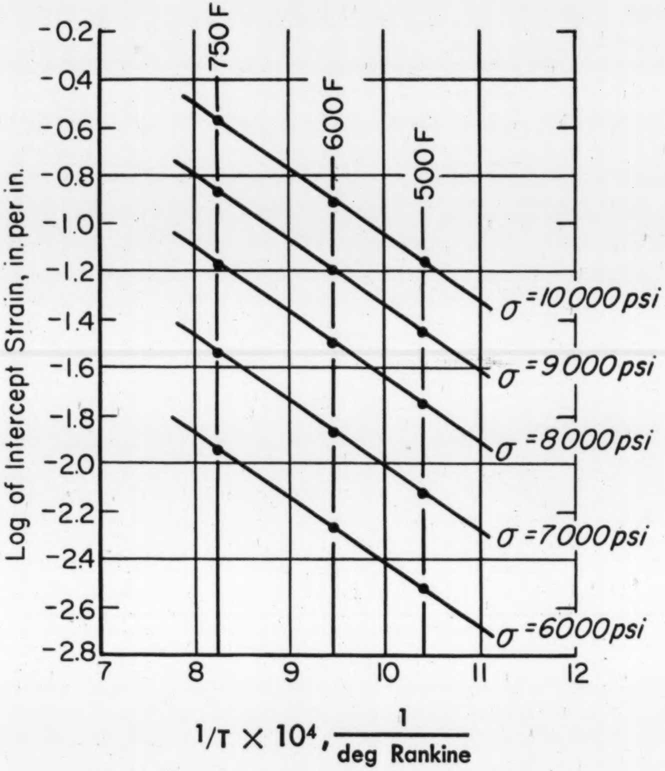

FIG. 17.—Intercept, ϵ_o, *versus* $\frac{1}{T}$ at Constant Stress.

and can be expressed as

$$\epsilon_0 = L\left(\frac{\sigma}{\sigma_0}\right)^m \ldots\ldots\ldots\ldots (2)$$

where m is a constant independent of temperature in the range from 500 to 750 F (260 to 400 C) for strains greater than 0.03 at 750 F, σ_0 is equal to 1 psi and L is a function of the temperature.

Creep Strain:

If the data in Fig. 9 are replotted using the square of the true stress, $\bar{\sigma}^2 \cong \sigma^2 (1 + \epsilon_0)^2$, as a function of the strain rate, $\dot{\epsilon}$, the curves in Fig. 18 are obtained. These curves suggest a theory for the rate of flow of zirconium similar to the reaction rate theories of Eyring, *et al.* (7) and Kauzmann (8).

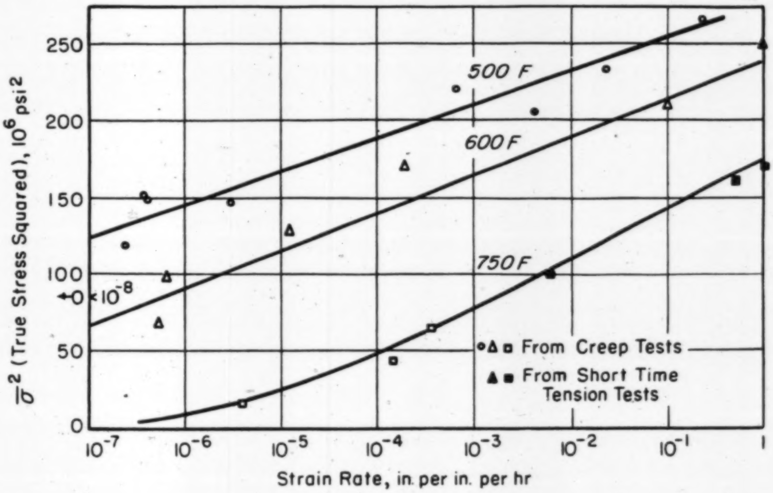

FIG. 18.—Square of True Stress *versus* Minimum Creep Rate (Experimental Points and Empirical Curves).

L is evaluated by plotting the log of the strain intercept, ϵ_0, at a given stress as a function of the reciprocal of the absolute temperature, T, in degrees Rankine, °R. The resultant straight lines, Fig. 17, are practically parallel and allow L to be expressed in the following form:

$$L = Ae^{-B/T} \ldots\ldots\ldots\ldots (3)$$

where A and B are constants.

Equation 2 can, therefore, be written

$$\epsilon_0 = Ae^{-B/T}\left(\frac{\sigma}{\sigma_0}\right)^m \ldots\ldots\ldots (4)$$

For these data, as plotted in Figs. 13 and 17, log $A = -23$, $B = 6.23 \times 10^3$ °R, $\sigma_0 = 1$ psi, and $m = 6.17$.

If it is assumed that the strain, ϵ, is a result of shearing motion which occurs in jumps of flow units, the size of which is not specified, then the strain rate is expressed as

$$\dot{\epsilon} = G'N \ldots\ldots\ldots\ldots (5)$$

where N is the number of jumps per unit of time and G' is a constant involving the geometry and orientation of the flow units. Let it be also assumed that an energy barrier exists to inhibit these jumps so that the flow units must be activated. According to the Boltzmann relation

$$N \propto e^{-E/kT} \ldots\ldots\ldots\ldots (6)$$

where E is the activation energy required for the flow units, T is the absolute temperature, and k is a constant for the temperature range involved. Finally, the assumption is made that the energy barrier is lowered in the direction of an applied shearing stress by an amount proportional to the elastic energy (elastic energy per unit of volume is proportional to $\bar{\sigma}^2$), while the barrier in the opposite direction is raised by an equal amount. Let the difference in the free energy of the unit of flow in the normal and activated states be ΔF, then in the direction of stress

$$E' = \Delta F - c\bar{\sigma}^2$$

and in the opposite direction

$$E'' = \Delta F + c\bar{\sigma}^2$$

then

$$\dot{\epsilon} = G(e^{-E'/kT} - e^{-E''/kT})$$

$$= 2Ge^{-\Delta F/kT} \sinh \frac{\bar{\sigma}^2}{c_3T} \quad .. \quad (7)$$

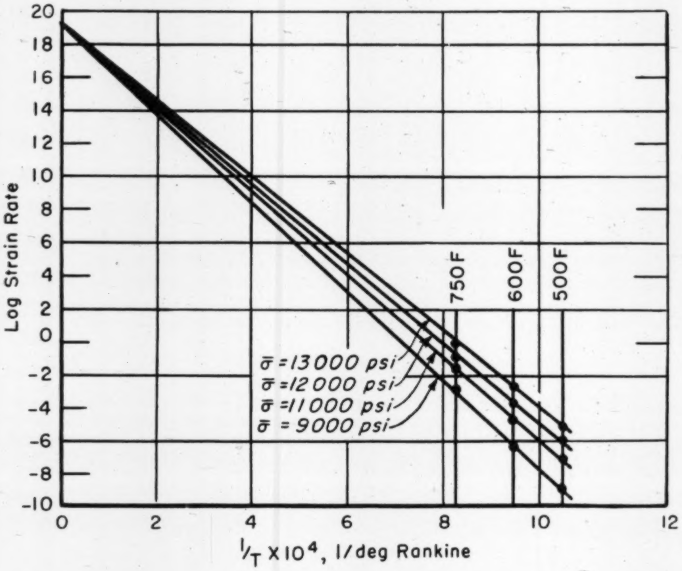

FIG. 19.—Strain Rate *versus* $\frac{1}{T}$ at Constant True Stress (from Fig. 17).

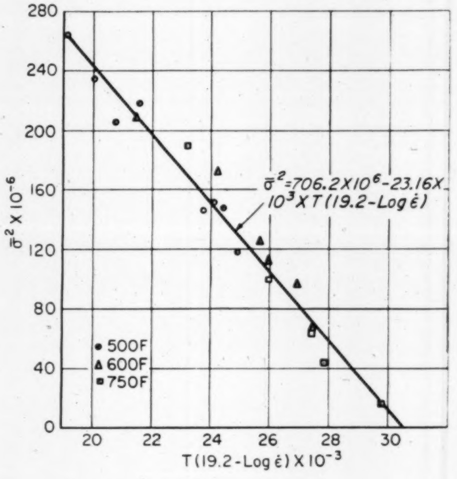

FIG. 20.—Square of True Stress *versus* Eq 9 Parameter.

This equation follows the hyperbolic sine law similar to that suggested by A. Nadai (9). Since $\Delta F = \Delta H - T\Delta S$ where ΔH is the heat of reaction and ΔS is the change in entropy, for large values of $\bar{\sigma}^2$ (therefore $\bar{\sigma}$ need not be large) Eq 7 reduces to

$$\dot{\epsilon} = Ge^{\Delta S/R}e^{-\Delta H/RT}e^{\bar{\sigma}^2/C_3T} \ldots\ldots \quad (8)$$

where R is the universal gas constant.

From the curves in Fig. 18, values of creep rate, $\dot{\epsilon}$, can be determined for given values of constant temperature and constant stress. In Fig. 19 the log of these creep rates is plotted as a function of the reciprocal of absolute temperature.

The straight lines drawn through these data can be made to pass through a common point at infinite temperature, $\frac{1}{T} = 0$. This type of behavior has also been found for high-temperature alloys (10). From Fig. 19, therefore, $Ge^{\Delta S/R}$ can be evaluated and can be shown to be a constant independent of temperature in this range. Equation 8 can now be written as

$$\frac{\Delta H}{R} - \frac{\bar{\sigma}^2}{C_3} = 2.3T(\log Ge^{\Delta S/R} - \log \dot{\epsilon}) \quad (9)$$

In Fig. 20, $\bar{\sigma}^2$ is plotted as a function of the parameter, T ($\log Ge^{\Delta S/R} - \log \dot{\epsilon}$). The data for all the creep tests distribute themselves about the same straight line. This indicates that ΔH is a constant and not a function of the stress. Thus the final equation for the strain rate can be written as a function of stress and temperature.

$$\dot{\epsilon} = C_1e^{-C_2/T} \sinh \frac{\bar{\sigma}^2}{C_3T} \ldots\ldots \quad (10)$$

This equation was used to draw the curves in Fig. 9. The data for the constant strain rate tests also fall reasonably close to this curve.

Equation 1 can now be written

$$\epsilon = Ae^{-B/T}\sigma^m + \left[C_1e^{-C_2/T} \sinh \frac{\sigma^2(1 + Ae^{-B/T}\sigma^m)^2}{C_3T}\right]t \quad (11)$$

where:

$A = 10^{-23}$,
$B = 6.23 \times 10^3$ °R,
$m = 6.17$,
$C_1 = e^{44.84}$ per hr,
$C_2 = \frac{\Delta \mathrm{H}}{\mathrm{R}} = 70{,}130$ °R,
$C_3 = 10{,}070$ psi^2 per °R,
T = temperature in degrees Rankine (°R) and,
t = time in hours.

expressing the total strain of the fully annealed, unalloyed, arc-melted zirconium as a function of nominal stress, temperature, and time.

One feature of the above relationships is that it may be possible to learn something about the fundamental mechanism and the size of the units of flow. This unit may be one atom or a group of atoms located within a grain or subgrain, or in the boundaries thereof, or may be the grains or subgrains themselves. From a study of the annealing process of unalloyed zirconium (1) and the above analysis of plastic flow it is suggested that the flow of zirconium is accomplished by fragmentation of the grains into a subgrain structure and by the relative motion at the boundaries of subgrains. No data are available on the activation energy for atomic mobility in zirconium. However, the value of activation energy calculated from C_2 in the above equations is 77,400 cal per mole and is of the correct order of magnitude for such a process. This value agrees very well with that predicted by Orr, Sherby, and Dorn (11).

The fact that the constant strain rate or short-time tension test data conform to Eq 10 indicates that the plastic flow with increasing load occurs by a mechanism similar to that at constant load.

CONCLUSIONS

The above test data and its analysis can be summarized in the following conclusions.

1. The creep strength of unalloyed zirconium depends on the state of anneal and increases with increasing hardness.

2. Because of the large plastic strain on loading, the creep strain up to 600 F (315 C) is small and can in most cases be neglected. Above 600 F, however, creep strength must be considered in design.

3. The creep strength drops almost linearly with temperature between 500 and 600 F (260 and 315 C) but begins to drop much more rapidly at some temperature above 600 F.

4. The rupture strength for 5000 hr is a similar function of the temperature and is the same as the creep strength for a rate of 10^{-6} per hr. This creep strength, therefore, can be used up to 750 F (400 C) for design purposes below a life of 5000 hr.

5. A general equation for the strain, ϵ, of unalloyed zirconium at constant load can be expressed up to the transition point in the form $\epsilon = \epsilon_0 + \dot{\epsilon}t$, where ϵ_0 is the strain intercept, $\dot{\epsilon}$ the creep rate, and t the time.

6. The strain intercept, ϵ_0, is a function of the stress and temperature. Up to 750 F (400 C) and above 7000 psi it follows the relationship $\epsilon_0 = Ae^{-B/T}\sigma^{m}$ where A, B, and m are constants, T the absolute temperature, and σ the nominal stress.

7. The flow mechanism of zirconium at constant load follows a rate process in which the creep rate can be expressed as:

$$\dot{\epsilon} = C_1 e^{-C_2/T} \sinh \frac{\sigma^3}{C_3 T}$$

where C_1, C_2, and C_3 are constants and $\bar{\sigma}$ is the true stress, defined as

$$\bar{\sigma} \cong \sigma(1 + \epsilon_0).$$

8. The activation energy for the rate process as calculated from this creep rate relationship is 77,400 cal per mole.

Acknowledgment:

The authors wish to thank B. Lustman, L. Castleman, and F. Forscher for their constructive suggestions, and M. Skantar and W. Babyak who performed the creep tests. This work was performed under Atomic Energy Commission Contract No. AT-11-1-GEN-14 at the Westinghouse Atomic Power Division.

REFERENCES

(1) R. K. McGeary and B. Lustman, "Kinetics of Thermal Reorientation in Cold Rolled Zirconium," *Journal of Metals*, Vol. 197, pp. 284–291 (1953).

(2) W. M. Bostrom and S. A. Kulin, "Recovery of Cold Worked Zirconium and Zirconium Alloys," *Zirconium and Zirconium Alloys*, Am. Soc. Metals (1953).

(3) M. J. Manjoine and N. A. Pollack, "Creep Rupture Tests of WAPD Grade I Iodide Crystal Bar Arc-Melted Zirconium at 260 C," Westinghouse Atomic Power Division Report No. 39, Nov., 1951.

(4) A. D. Schwope and G. I. Muehlenkamp, "Tensile Creep Properties at 500 F of Zirconium . . . ," Battelle Memorial Institute Report No. 779, Nov. 1, 1952.

(5) M. J. Manjoine, "New Machines for Creep and Creep Rupture Tests," *Transactions*, Am. Soc. Mechanical Engrs., Vol. 67, pp. 111–116 (1945).

(6) P. G. McVetty, "The Interpretation of Creep Tests," *Proceedings*, Am. Soc. Testing Mats., Vol. 34, Part II, p. 105 (1934).

(7) S. Glasstone, K. J. Laidler and H. Eyring, "The Theory of Rate Processes," McGraw-Hill, New York, N. Y. (1941).

(8) W. Kauzmann, "Flow of Solid Metals from the Standpoint of Chemical Rate

Theory," *Transactions*, Am. Inst. Mining and Metallurgical Engrs., Vol. 143, pp. 57–81 (1941).

(9) A. Nadai, "The Influence of Time Upon Creep. The Hyperbolic Sine Creep Law," Stephen Timoshenko Anniversary Volume, The MacMillan Company, New York, N. Y., (1938).

(10) F. Larson and J. Miller, "A Time-Temperature Relationship for Rupture and Creep Stresses," *Transactions*, Am. Soc. Mechanical Engrs., Vol. 74, pp. 765–775 (1952).

(11) B. L. Orr, O. D. Sherby and J. E. Dorn, "Correlations of Rupture Data for Metals at Elevated Temperatures," *Transactions*, Am. Soc. Metals, Vol. 46 (1954); also "Creep Correlations of Metals at Elevated Temperatures," *Journal of Metals*, Vol. 6, No. 1, pp. 71–80 (Jan., 1954).

TENSILE AND CREEP PROPERTIES AT ELEVATED TEMPERATURES OF SOME MAGNESIUM-BASE WROUGHT ALLOYS*

By H. Baker[1]

Synopsis

This paper makes available to the designer properties of commercial magnesium-base wrought alloys at elevated temperatures. The following alloys[2] are discussed:

Extruded AZ31B-F, AZ61A-F, and M1A-F;
Rolled sheet AZ31A-O, AZ31A-H24, M1A-O, and M1A-H24.

Of the three extrusion alloys, AZ61A-F has the highest tensile properties up to about 400 to 500 F. Of the four sheet alloys, AZ31A-H24 has the highest tensile properties up to about 200 to 300 F, above which M1A-H24 has the highest tensile properties. Generally, except for specific ranges of extension, time, and temperature, M1A alloy has the highest creep properties. Before the best material for a part may be selected, the operating conditions of that part must be known.

In 1946, Moore and McDonald[3] presented data on magnesium forgings, extrusions, and sheet. McDonald[4] presented further data on magnesium forgings in 1948. The purpose of this paper is to make available additional elevated-temperature data on commercial magnesium-base wrought alloys. A companion paper[5] presents similar data for magnesium-base sand-casting alloys.

The alloys under investigation are listed in Table I. The material for this investigation was taken from commercial stock. The methods of tension and creep testing have been discussed in detail in a previous publication.[3]

Effect of Temperature on Tensile Properties

The effect of testing temperature on the tensile properties of the seven wrought magnesium alloys is shown in Figs. 1 and 2. Of the three extrusion alloys tested, AZ61A-F has the highest room-temperature properties. These properties do not fall off appreciably until above 200 F. The strength-tempera-

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13–18, 1954.

[1] Research and Development Engineer, Metallurgical Laboratories, The Dow Chemical Co., Midland, Mich.

[2] Tentative Specifications for Magnesium-Base Alloy Bars, Rods, and Shapes (B 107 – 53 T) (for extruded alloys), and Tentative Specifications for Magnesium-Base Alloy Sheet (B 90 – 51 T) (for rolled sheet alloys), 1953 Supplement to Book of ASTM Standards, Part 2, p. 134, and 1952 Book of ASTM Standards, Part 2, p. 533, respectively.

[3] A. A. Moore and J. C. McDonald, "Tensile and Creep Strengths of Some Magnesium-Base Alloys at Elevated Temperature," *Proceedings*, Am. Soc. Testing Mats., Vol. 46, p. 970 (1946).

[4] J. C. McDonald, "Tensile, Creep, and Fatigue Properties at Elevated Temperatures of Some Magnesium-Base Alloys," *Proceedings*, Am. Soc. Testing Mats., Vol. 48, p. 737 (1948).

[5] K. E. Nelson, "Tensile and Creep Properties at Elevated Temperatures of Some Magnesium-Base Sand-Casting Alloys," this volume, p. 1081.

TABLE I.—MATERIALS TESTED.

Alloy and Temper		ASTM Specification	Condition	Nominal Composition, per cent			Tensile Strength, psi		Tensile Yield Strength, psi		Compressive Yield Strength, psi		Elongation, per cent	
ASTM	Dow			Aluminum	Zinc	Manganese	Typical	Minimum	Typical	Minimum	Typical	Minimum	Typical	Minimum
AZ31B-F	FS1-F	B 107 – 53 T	As extruded	3.0	1.0	...	38 000	35 000	29 000	22 000	14 000	12 000	15	10
A61A-F	J1-F	B 107 – 53 T	As extruded	6.5	1.0	...	45 000	40 000	33 000	24 000	19 000	14 000	16	10
M1A-F	M-F	B 107 – 53 T	As extruded	...	...	1.2	37 000	32 000	26 000	...	12 000	...	11	3
AZ31A-O	FS1-O	B 90 – 51 T	Annealed	3.0	1.0	...	37 000	32 000	22 000	15 000	16 000	12 000	21	12
AZ31A-H24	FS1-H24	B 90 – 51 T	Hard rolled	3.0	1.0	...	42 000	39 000	32 000	29 000	26 000	24 000	15	4
M1A-O	M-O	B 90 – 51 T	Annealed	...	...	1.2	34 000	28 000	17 000	...	11 000	...	16	12
M1A-H24	M-H24	B 90 – 51 T	Hard rolled	...	...	1.2	36 000	32 000	27 000	22 000	18 000	...	7	3

ture relationship of AZ31B-F is similar, though not quite so high. The strength of M1A-F falls off rapidly above room temperature, but it decreases at a lower rate at higher temperatures and has about the same strength as AZ61A-F and AZ31B-F around 400 to 500 F.

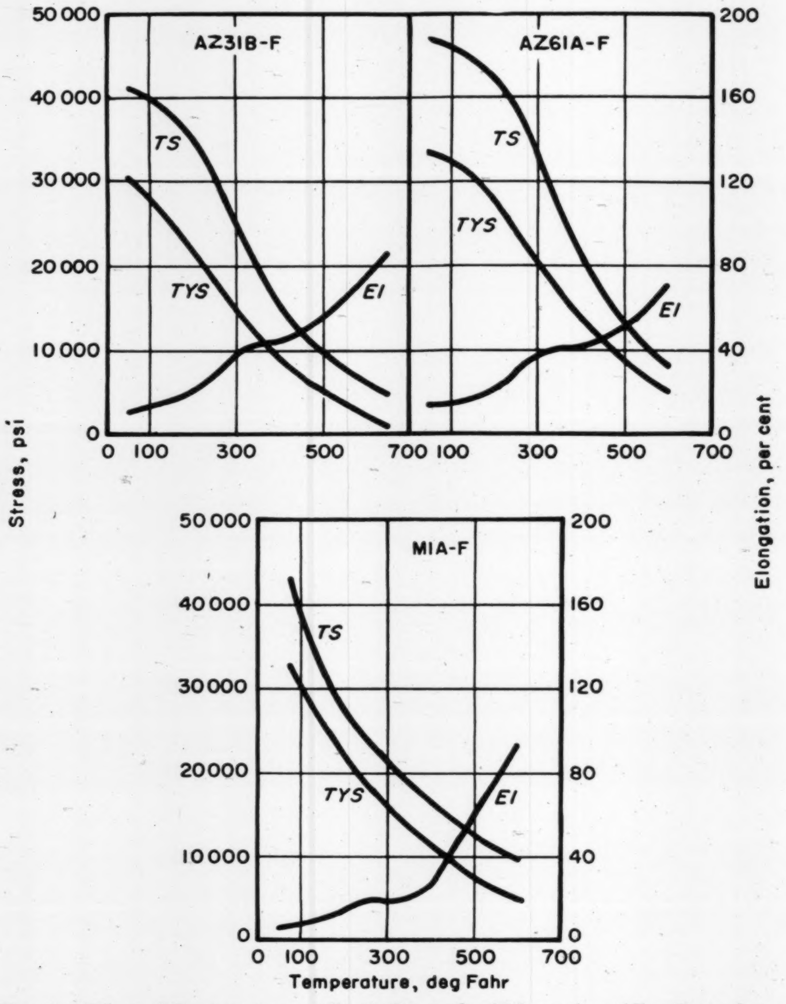


FIG. 1.—Effect of Temperature on Static Strength of Magnesium Alloy Extrusions.

Of the four sheet alloys tested, AZ31A-H24 has the highest room-temperature properties. At 200 F and above, M1A-H24 has the highest tensile yield strength, and above 300 F it also has the highest tensile strength and compressive yield strength.

CREEP TESTS

Total extension was used to compare the creep characteristics of the various alloys. Total extension represents the extension that takes place at the test temperature from the condition of zero load. This includes both elastic and plastic extension obtained during loading, as well as the subsequent creep, but it does not include extension due to the heating of the specimen to the test temperature. In Figs. 3 through 9 the stresses necessary to produce 0.1, 0.2, 0,5, and 1.0 per cent total extension are plotted for various times and temperatures.

The various alloys may be compared in creep, from the graphs of stress *versus* time for a given total extension and temperature (Figs. 3 to 9). Of the three extrusion alloys in the range of times tested, M1A-F shows the least variation of stress with time. The other two alloys have a greater variation of stress with time, with AZ61A-F always showing higher values than AZ31B-F. Of the four sheet alloys, M1A-O shows the least variation with time. The variations of the other three alloys are greater and generally comparable to each other. The different shapes of these curves render any generalized creep-strength comparison very difficult.

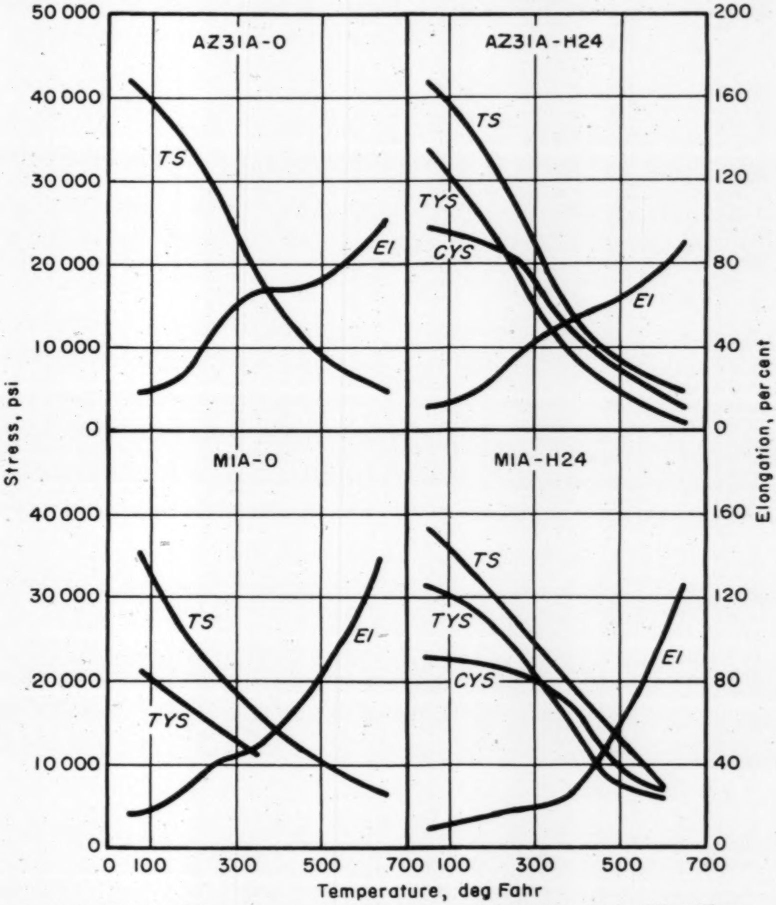


FIG. 2.—Effect of Temperature on Static Strength of Magnesium Alloy Sheet.

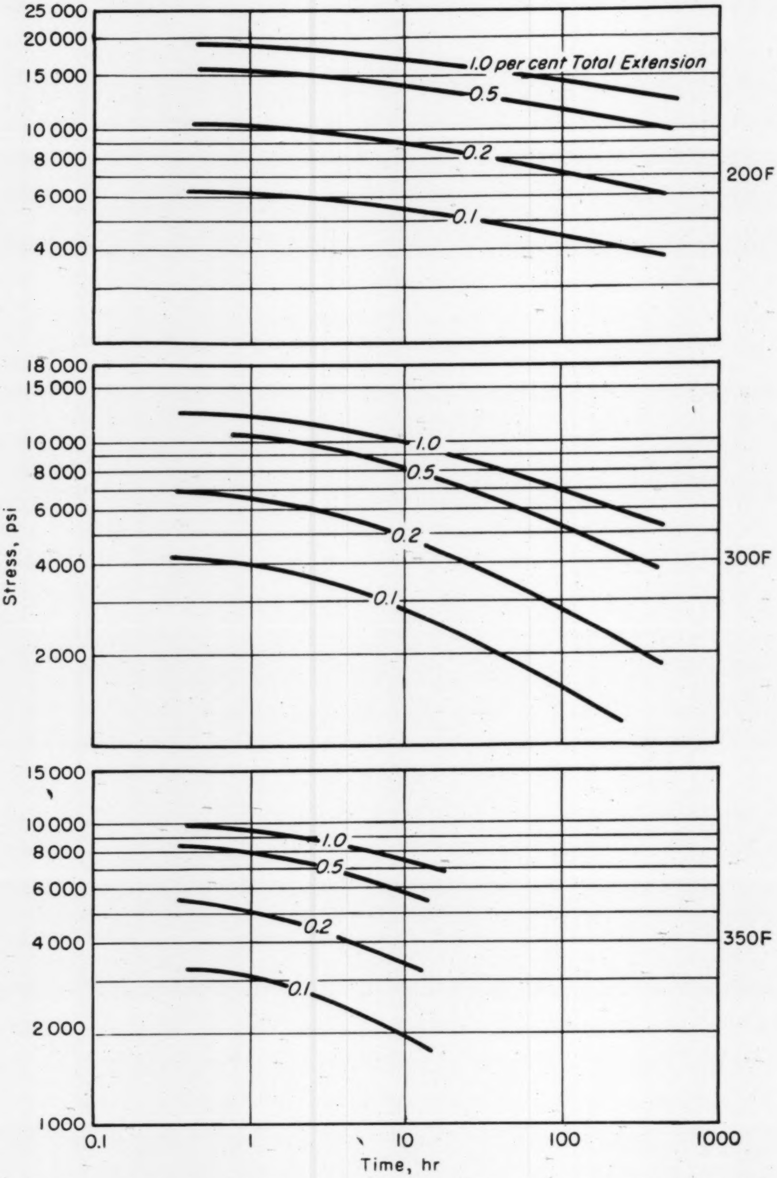


FIG. 3.—Stress for Various Total Extensions of AZ31B-F Magnesium Alloy Extrusions.

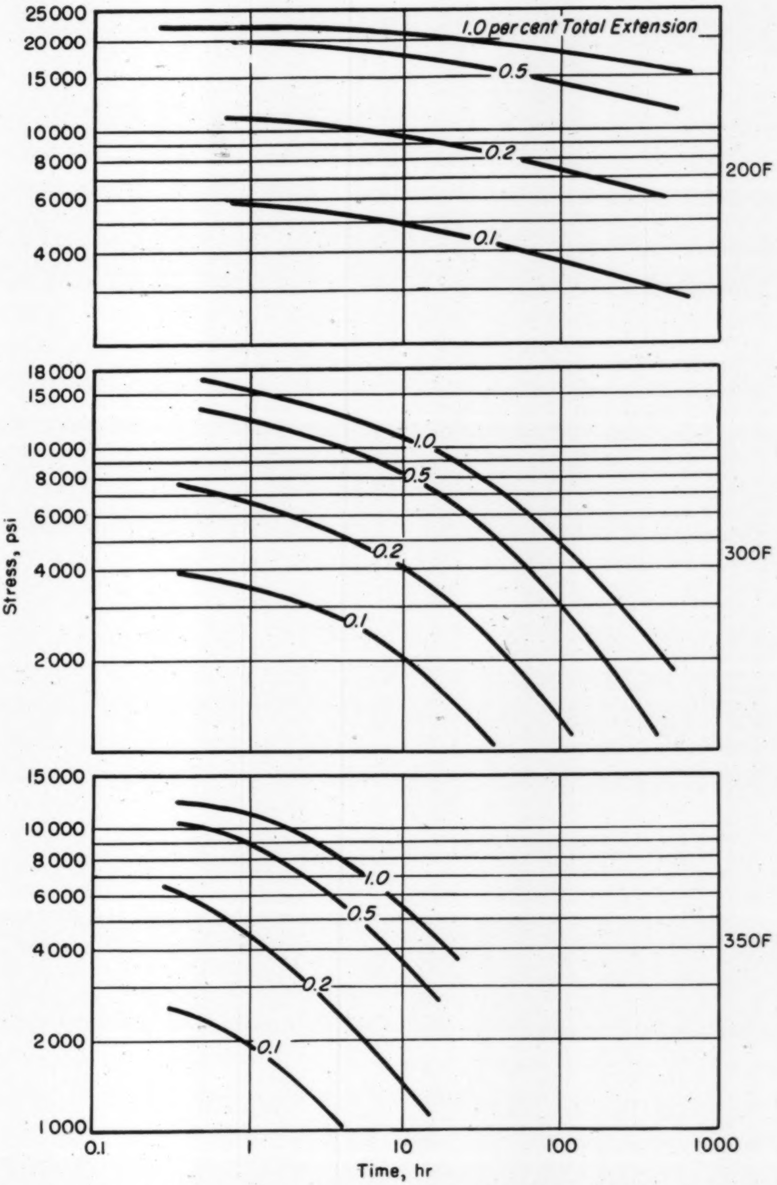


FIG. 4.—Stress for Various Total Extensions of AZ61A-F Magnesium Alloy Extrusions.

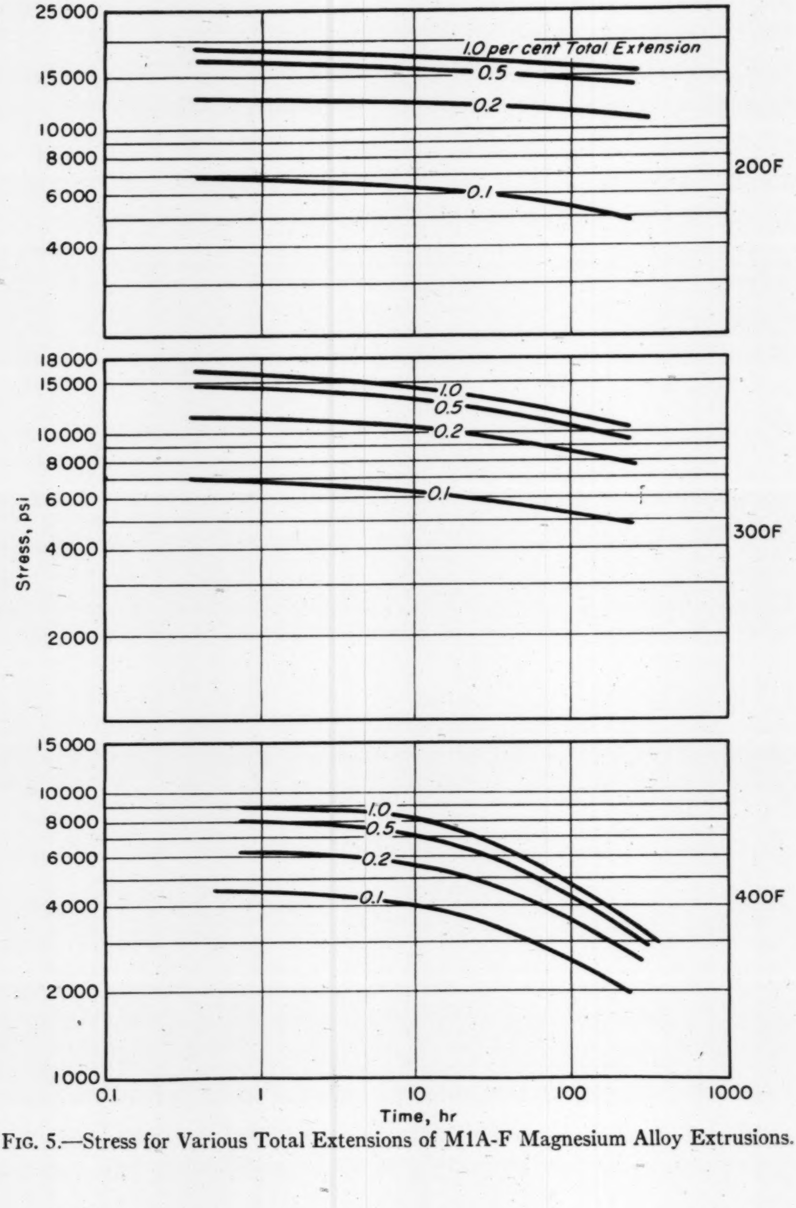


FIG. 5.—Stress for Various Total Extensions of M1A-F Magnesium Alloy Extrusions.

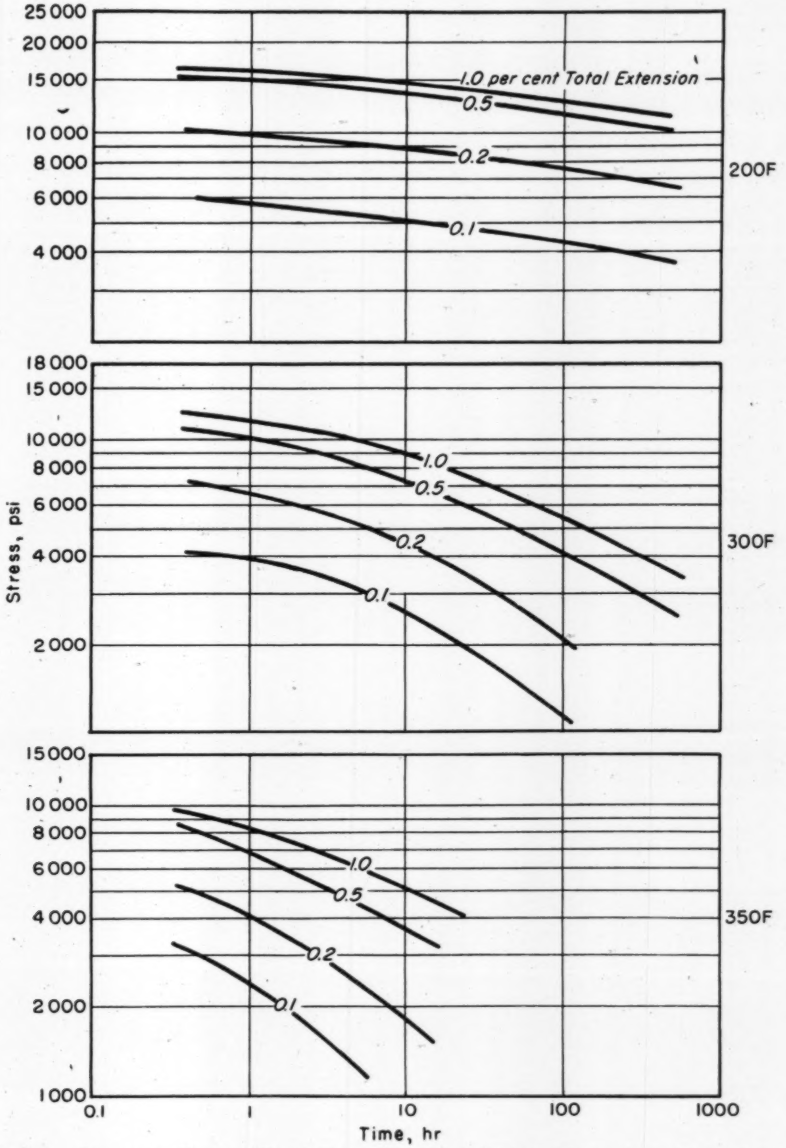


FIG. 6.—Stress for Various Total Extensions of AZ31A-O Magnesium Alloy Sheet.

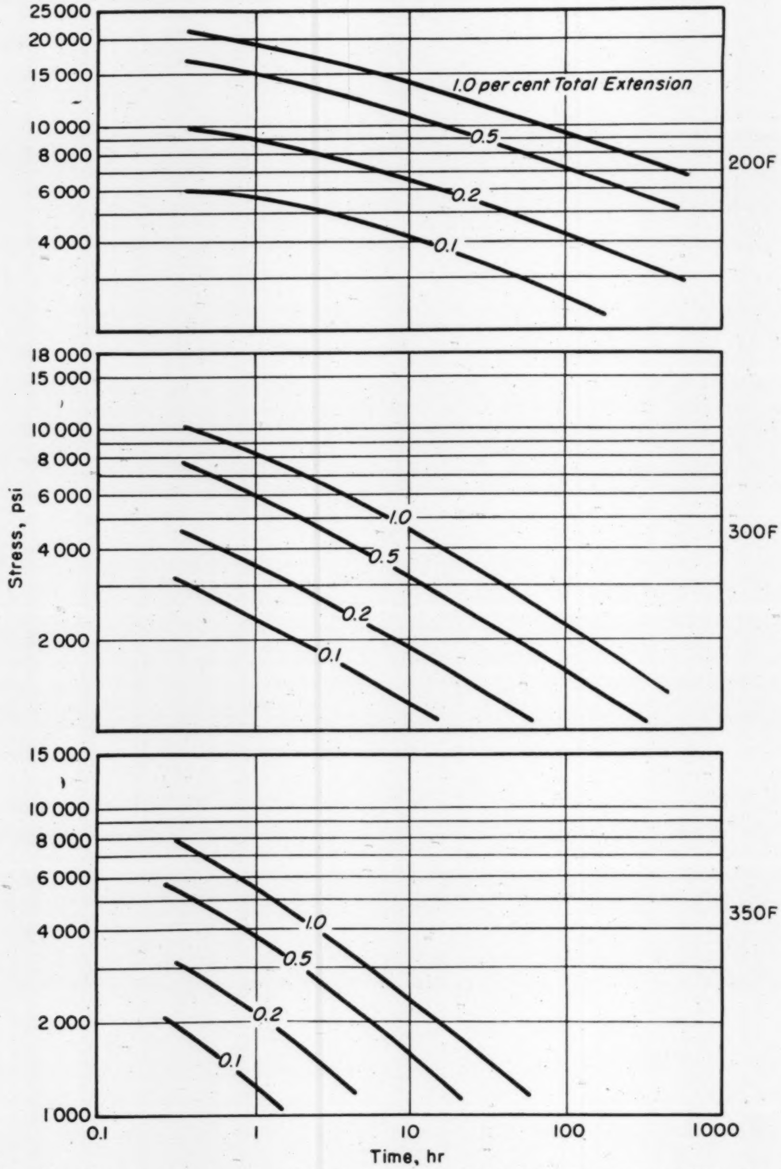


FIG. 7.—Stress for Various Total Extensions of AZ31A-H24 Magnesium Alloy Sheet.

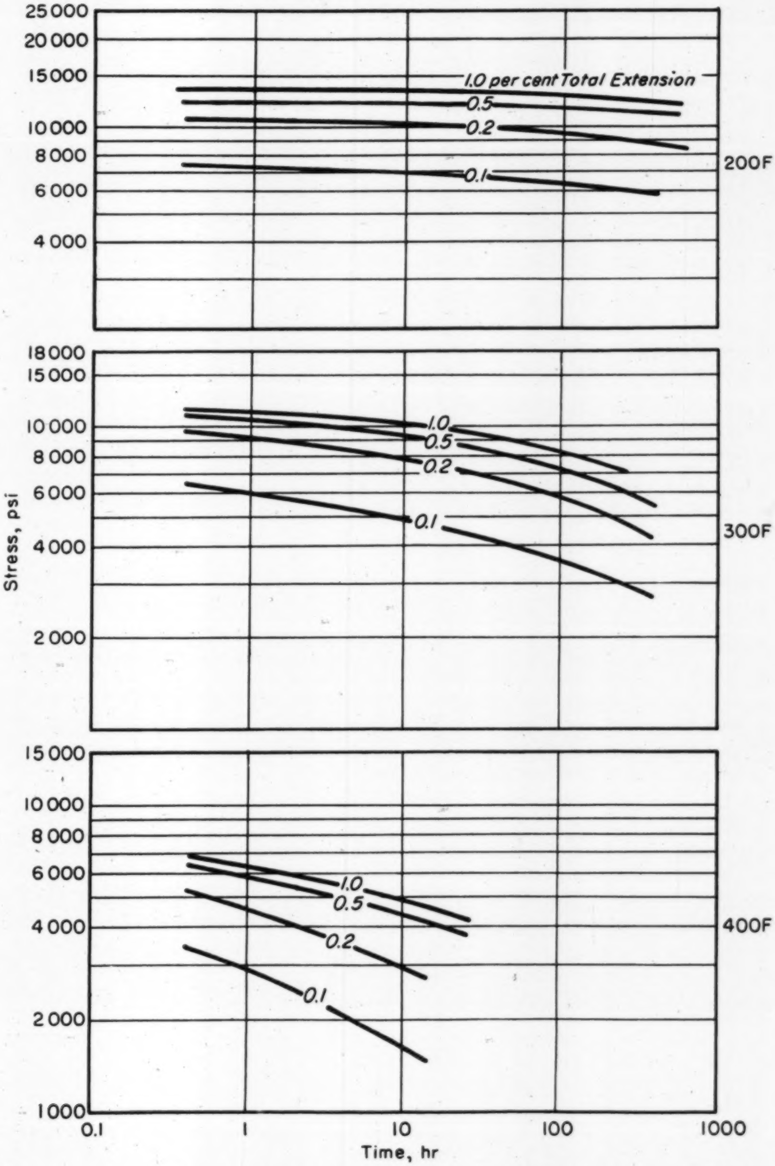


FIG. 8.—Stress for Various Total Extensions of M1A-O Magnesium Alloy Sheet.

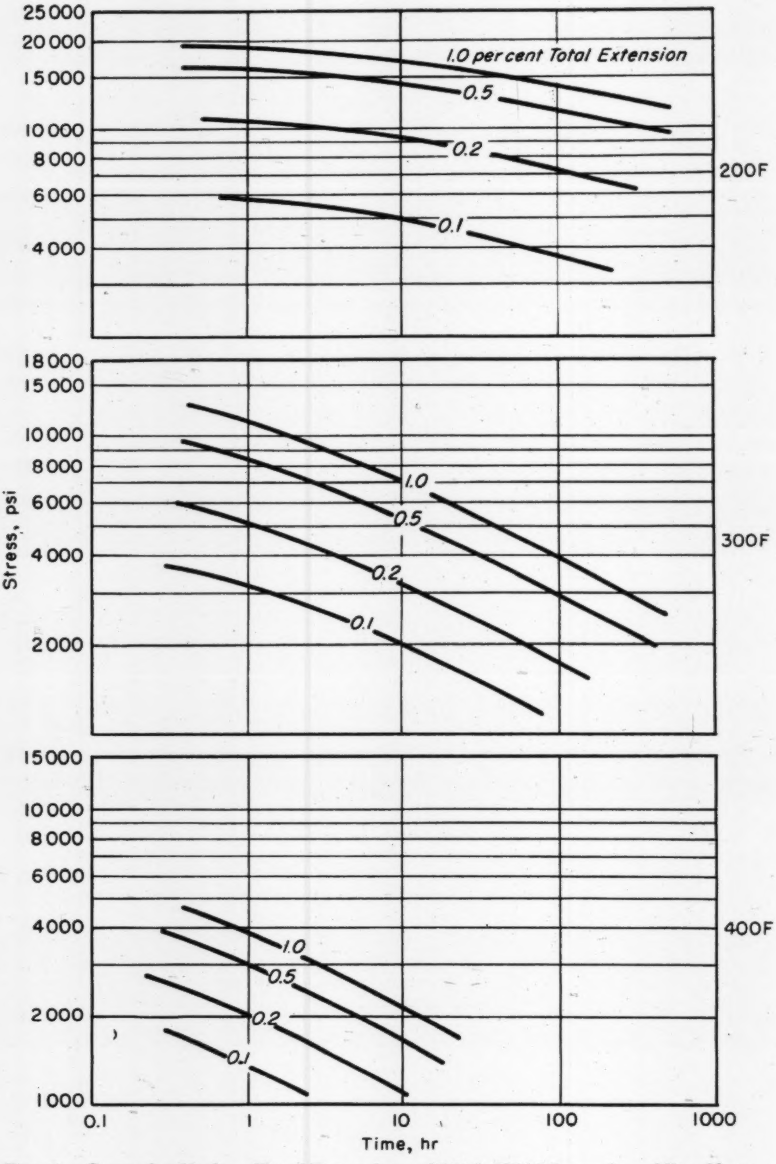


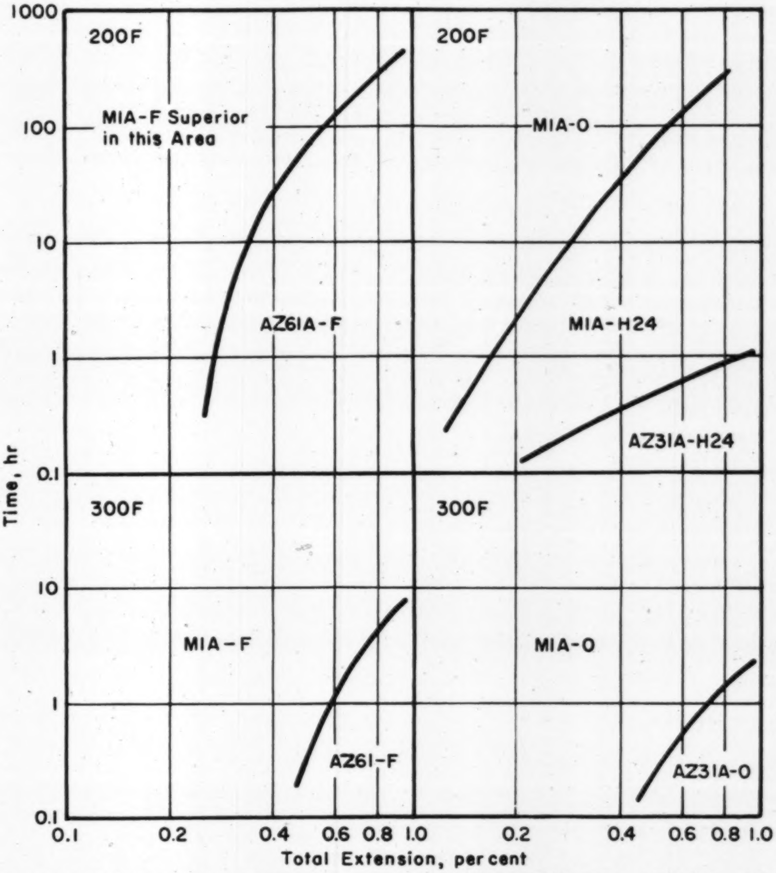
FIG. 9.—Stress for Various Total Extensions of M1A-H24 Magnesium Alloy Sheet.

DISCUSSION

Before the best material for a part may be selected, the operating conditions of that part must be known. These conditions are the time and temperature of operation, the allowable deformation, and the magnitude of the load the part must carry. If these conditions are known, the data in this paper should aid the design engineer in choosing an alloy for the part.

A general comparison of the creep strength of the several alloys can be found in Fig. 10. If, for instance, a designer concluded that the requirements of a certain extruded part were that it should have no more than 0.2 per cent total extension in 10 hr at 200 F, then from Fig. 10 he would see that, of the three extrusion alloys reported, M1A-F would have the highest allowable stress. Figure 5 shows the stress for those condi-

(*a*) M1A-F, AZ61A-F, AZ31B-F extrusions.
(*b*) M1A-O, M1A-H24, AZ31A-O, AZ31-A-H24 sheet.



(*c*) M1A-F, AZ61A-F, AZ31B-F extrusions.
(*d*) M1A-O, M1A-H24, AZ31A-O, AZ-31A-H24 sheet.

FIG. 10.—Comparison of Creep Strength of Some Magnesium-Base Wrought Alloys.

tions to be about 12,000 psi. If the requirements for the extruded part were that it should have no more than 1.0 per cent total extension in 10 hr at 200 F, AZ61A-F would have the highest allowable stress—about 22,000 psi. The comparable stress for M1A-F with the same requirements of time, total extension, and temperature would be only about 17,500 psi. This points up the importance of knowing the operating conditions before selecting the material.

It should be recognized that the graphs in this paper were prepared from data obtained from a few batches of metal, and that other batches will doubtless yield results slightly at variance with these. However, the graphs herein presented do represent results averaged from commercially acceptable material.

TENSILE AND CREEP PROPERTIES AT ELEVATED TEMPERATURES OF SOME MAGNESIUM-BASE SAND-CASTING ALLOYS*

By K. E. Nelson[1]

Synopsis

The tensile properties of several magnesium sand-casting alloys are compared at room temperature and at elevated temperatures as a function of time of exposure at elevated temperatures. Results of creep tests for various times, temperatures, and amounts of extensions up to 1 per cent are also presented. These data are presented in such a manner that the design engineer may choose the composition for a part, assuming that he has some indication of the operating conditions of the part.

Considerable information has been published on the properties of magnesium sand-casting alloys at elevated temperatures. A rather complete list of references has been given in an earlier paper (**1**).[2] McDonald presented a paper in 1948 (**2**) before this Society on the elevated-temperature properties of magnesium alloys currently in use at that time. The purpose of the work described in this paper is to furnish data on magnesium sand-casting alloys developed since the writing of the foregoing paper, including the magnesium-zinc-zirconium, magnesium - rare earth metal - zirconium, and the newest class of elevated-temperature magnesium alloys, the magnesium-thorium-zirconium type. For comparative purposes, a representative magnesium-aluminum-zinc alloy is included. An attempt has been made to present the data in such a manner as to be useful to the design engineer.

The alloys under investigation are listed in Table I with the chemical composition, heat treatment, and specified minimum room-temperature tensile properties currently used by The Dow Chemical Co. These compositions and minimum values are covered in ASTM Specification B 80 – 53 T[3] in the case of the first six alloys listed. The two thorium-containing alloys are not covered by any major specification writing agency.

A recent publication (**3**) indicates that there are three classes of magnesium sand-casting alloys currently being produced for use in applications such as jet engines. These three classes are: (1) magnesium-aluminum-zinc, (2) magnesium - rare earth metal - zirconium, and (3) magnesium-thorium-zirconium. In a

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13–18, 1954.

[1] Research and Development Engineer, Casting Section, Metallurgical Laboratories, The Dow Chemical Co., Midland, Mich.

[2] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 1097.

[3] Tentative Specifications for Magnesium-Base Alloy Sand Castings (B 80 – 53 T), 1953 Supplement to Book of ASTM Standards, Part 2, p. 129.

TABLE I.—MATERIALS TESTED.

Alloy	Heat Treatment	Composition Range, per cent						Tensile Strength, psi		Yield Strength, 0.2 per cent Offset, psi		Elongation, per cent	
		Aluminum	Zinc	Rare Earth Metal[a]	Thorium	Manganese (min)	Zirconium	Typical	Minimum	Typical	Minimum	Typical	Minimum
C-T6 (AZ92A-T6)	500 to 770 F (max) in 2 hr 770 F (max) for 18 hr Air cooled. 500 F for 4 hr	8.3–9.7	1.6–2.4	...	...	0.10	...	40 000	34 000	23 000	18 000	2	1
ZK51A-T5	350 F for 12 hr	...	3.6–5.5	...	...	...	0.5–1.0	40 000	34 000	26 000	20 000	8	5
EK30A-T6	1060 F (max) for 18 hr Air cooled. 400 F for 16 hr	...	...	2.5–4.0	...	...	0.2 min	23 000	20 000	16 000	14 000	3	2
EZ33A-T5	420 F for 5 hr	...	2.0–3.5	2.5–4.0	...	...	0.50–1.0	23 000	20 000	16 000	14 000	3	2
EK41A-T6	1060 F (max) for 18 hr Air cooled. 400 F for 16 hr	...	...	3.0–5.0	...	...	0.40–1.0	25 000	22 000	18 000	16 000	2	1
EK41A-T5	400 F for 16 hr	...	...	3.0–5.0	...	...	0.40–1.0	23 000	20 000	16 000	14 000	1	...
HK31XA-T6	1060 F (max) for 2 hr Air cooled. 400 F for 16 hr	...	...	...	2.5–4.0	...	0.50–1.0	31 000	26 000	16 000	13 000	6	4
HZ32XA-T5	600 F for 16 hr	...	1.7–2.5	...	2.5–4.0	...	0.50–1.0	29 000	26 000	15 000	13 000	6	4

[a] Rare earth metals are added as mischmetal (approximately 50 per cent cerium, 22 per cent lanthanum, 18 per cent neodymium, 6 per cent praseodymium, and lesser amounts of other rare earths and impurities).

NOTE.—Tensile properties are for separately cast test bars.

TABLE II.—EFFECT OF TESTING TEMPERATURE ON THE TENSILE PROPERTIES OF MAGNESIUM SAND-CASTING ALLOYS.[a]

Separately cast test bars.

Alloy	70 F			200 F			300 F			400 F			500 F			600 F		
	TS	YS	Elong.	TS	YS	Elong.	TS	YS	Elong.	TS	YS	Elong.	TS	YS	Elong.	TS	YS	Elong.
C-T6 (AZ92A-T6)	40 000	24 000	2	39 000	21 000	14	28 000	17 000	28	19 000	12 000	42	13 000	8 000	62	7 000	5 000	94
ZK51A-T5	40 000	26 000	8	30 000	21 000	12	23 000	17 000	14	17 000	13 000	16	12 000	9 000	16	8 000	6 000	16
EK30A-T6	20 000	15 000	2	20 000	15 000	4	20 000	14 000	8	18 000	12 000	14	17 000	12 000	35	12 000	8 000	70
EZ33A-T5	24 000	16 000	3	23 000	15 000	6	23 000	13 000	10	21 000	11 000	22	18 000	10 000	31	12 000	8 000	50
EK41A-T6	26 000	20 000	3	...	...	...	23 000	18 000	8	22 000	17 000	10	20 000	14 000	17	13 000	9 000	56
EK41A-T5	22 000	17 000	1	...	...	...	20 000	14 000	7	19 000	12 000	16	17 000	11 000	33	11 000	7 000	57
HK31XA-T6	33 000	16 000	8	...	...	...	...	...	...	22 000	14 000	19	24 000	14 000	20	19 000	12 000	20
HZ32XA-T5	31 000	15 000	8	...	...	...	...	...	...	16 000	9 000	36	13 000	8 000	40	11 000	7 000	36

[a] TS = tensile strength, psi. YS = yield strength, 0.2 per cent offset, psi. Elong. = elongation in 2 in., per cent.

discussion by Nelson of a paper by Ball, *et al.* (4), these classes are briefly compared. Another system of alloys that has received increased interest in the United States (5, 6), Canada (7, 8), and England (9, 10) contains magnesium-zinc-zirconium. In Canada, the composition preference appears to be ZK61A-T6, whereas in the United States and in England, the preference is for ZK51A-T5 or, using English terminology, Z5Z, and would be expected to be used at similar operating temperatures. The alloys designated EZ33A-T5 and HZ32XA-T5 are the same as the English alloys designated ZRE1 and ZT1, respectively.

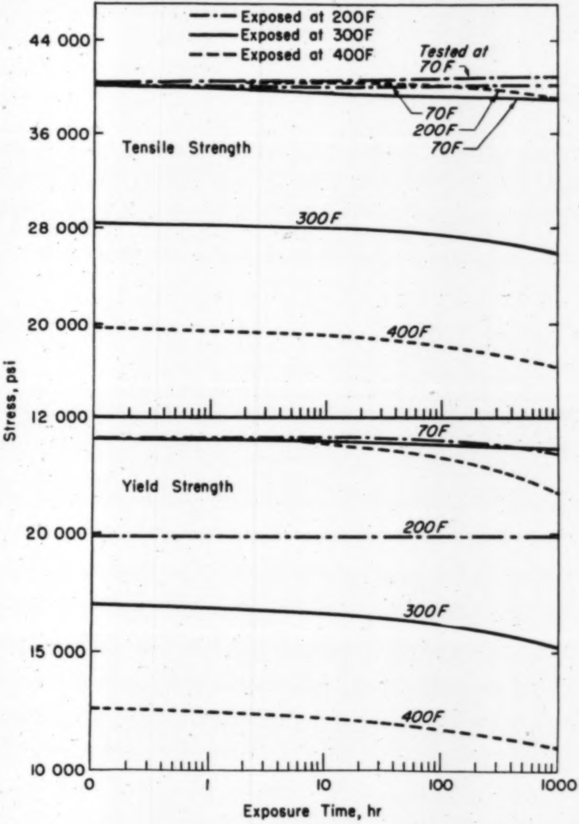

FIG. 1.—Effect of Exposure at Elevated Temperatures on the Tensile Properties at 70, 200, 300 and 400 F of AZ92A-T6 Alloy. Separately cast test bars.

In order to evaluate properly the various alloys, tests were made to obtain the room-temperature and elevated-temperature tensile properties as a function of time of exposure at elevated temperatures. Creep data were obtained after testing for various times, temperatures, and amounts of extension up to 1 per cent. Creep tests of 100 hr were made after exposures without applied stress for various times at elevated temperatures.

A companion paper (11) compares properties of magnesium-base sheet and extrusion alloys in a manner similar to that presented in this paper.

PROCEDURE

Methods used to produce the alloys evaluated have been thoroughly described in earlier publications and need no further description (**12-16**). Standard separately cast test bars with $\frac{1}{2}$-in. diameter reduced sections were poured, using molds made of regular magnesium foundry sand. The heat treatments and exposure treatments were done in electrically heated laboratory furnaces controlled to ±5 F. Sulfur dioxide gas was introduced into the solution-heat-treatment furnace in the usual manner to prevent any reaction between the atmosphere and metal.

Methods of tension and creep testing have been discussed in detail in previous publications (**17, 18**).

EFFECT OF EXPOSURE AT ELEVATED TEMPERATURES ON TENSILE PROPERTIES

The effect of testing temperature on the tensile properties of the sand-cast magnesium alloys under investigation is shown in Table II.

The effect of exposure is presented in Figs. 1 to 4.

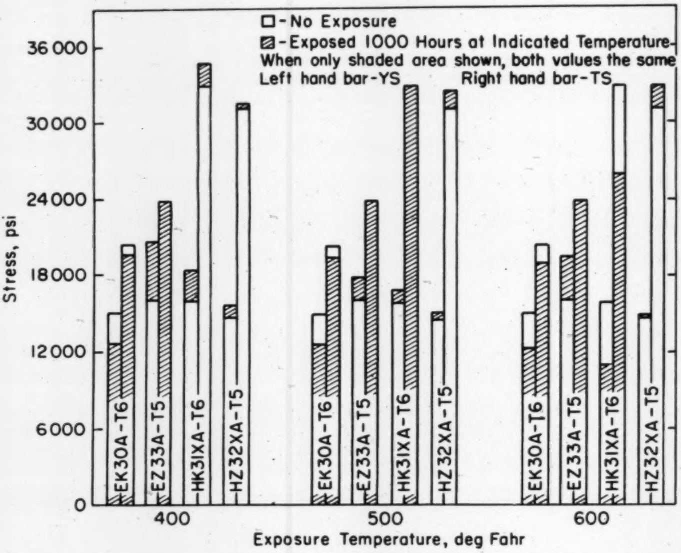

FIG. 2.—Effect of Exposure at Elevated Temperatures on the 70-F Tensile Properties of Magnesium-Rare Earth Metal-Zirconium and Magnesium-Thorium-Zirconium Alloys. Separately cast test bars.

The properties of AZ92A-T6 decrease somewhat with exposure temperature. At 400 F after 1000-hr exposure, they are comparable to EK30A and HZ32XA alloys tested after the same exposure. It is evident from the results that the presence of zinc in both the magnesium-rare earth metal-zirconium and the magnesium-thorium-zirconium alloys greatly improves their strength stability at elevated temperatures.

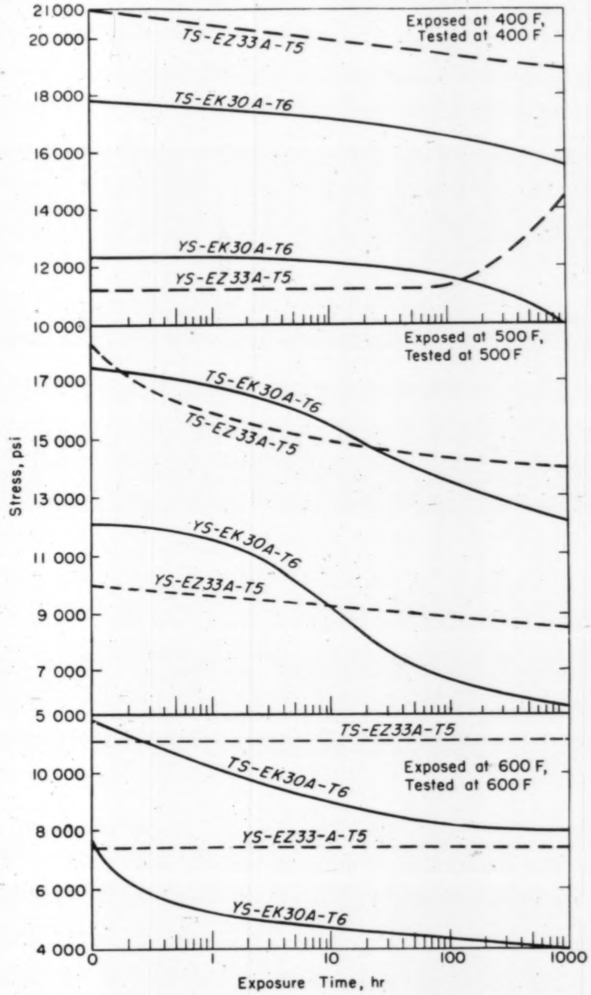

FIG. 3.—Effect of Exposure at Elevated Temperatures on the Tensile Properties at 400, 500, and 600 F of EK30A-T6 and EZ33A-T5 Alloys. Separately cast test bars.

1000-HR CREEP TESTS

Total extension was considered the most significant parameter for design purposes in comparing creep characteristics among the various alloys. Total extension represents the extension that takes place from the condition of zero load. This includes both the elastic and plastic extension obtained during loading, as well as the subsequent creep. In Figs. 5 to 11, the stresses necessary to produce 0.1, 0.2, 0.5, and 1.0 per cent total extension are plotted for times from 0 to 1000 hr of testing at various temperatures. The 0-hr points were derived from the autographic stress-strain curves obtained with the short-time tension tests.

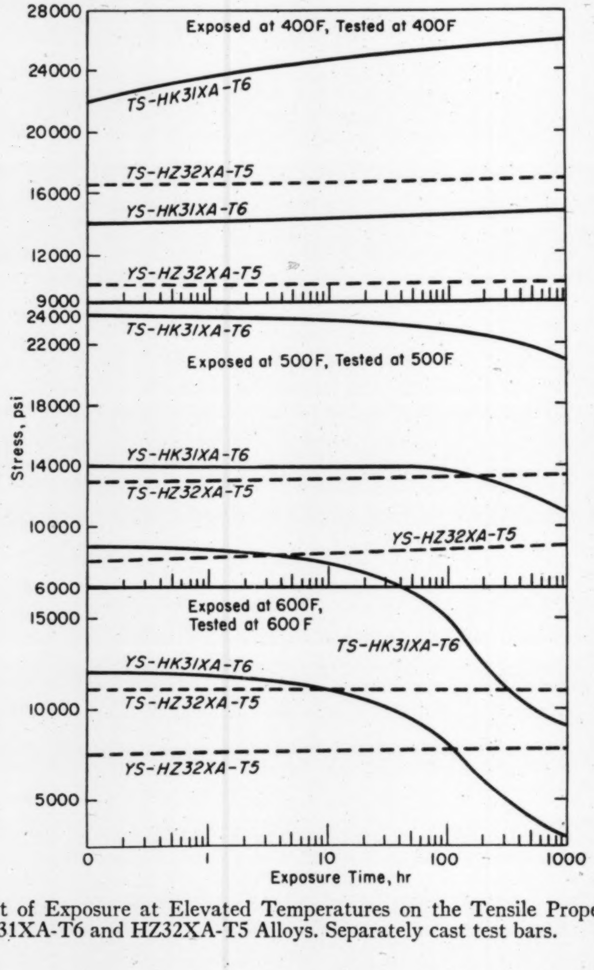

FIG. 4.—Effect of Exposure at Elevated Temperatures on the Tensile Properties at 400, 500, and 600 F of HK31XA-T6 and HZ32XA-T5 Alloys. Separately cast test bars.

The following tests were made:

AZ92A-T6 at 200, 300, and 400 F.
ZK51A-T5 at 200, 300, and 400 F.
EK30A-T6 at 400, 500, and 600 F.
EZ33A-T5 at 400, 500, and 600 F.
EK41A-T6 at 400 and 600 F.
EK41A-T5 at 400 F.
HK31XA-T6 at 400, 500, and 600 F.
HZ32XA-T5 at 400, 500, and 600 F.

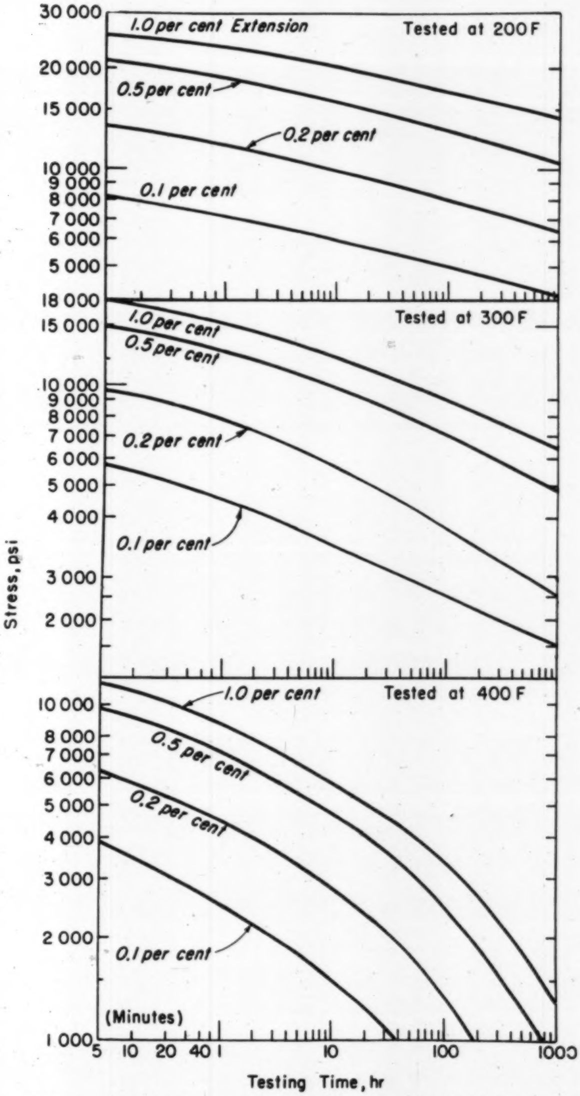

FIG. 5.—Stress for Various Total Extensions at 200, 300, and 400 F. Separately cast test bars of AZ92A-T6 Alloy.

It can be seen on Figs. 5 and 6 that the creep resistance of both AZ92A-T6 and ZK51A-T5 alloys decreases rapidly as the temperature of testing is increased from 200 to 400 F. The creep resistance of the magnesium-rare earth metal-zirconium alloys also decreases rapidly as testing temperature is increased from 400 to 600 F. Since the alloys AZ92A-T6 and ZK51A-T5 will not withstand high stresses for long times above 400 F, data above this temperature are not presented. In the case of the rare earth metal and thorium-containing alloys, data are not given for temperatures below 400 F because there are, at most, only a few applications that could take advantage of the slight superiority these

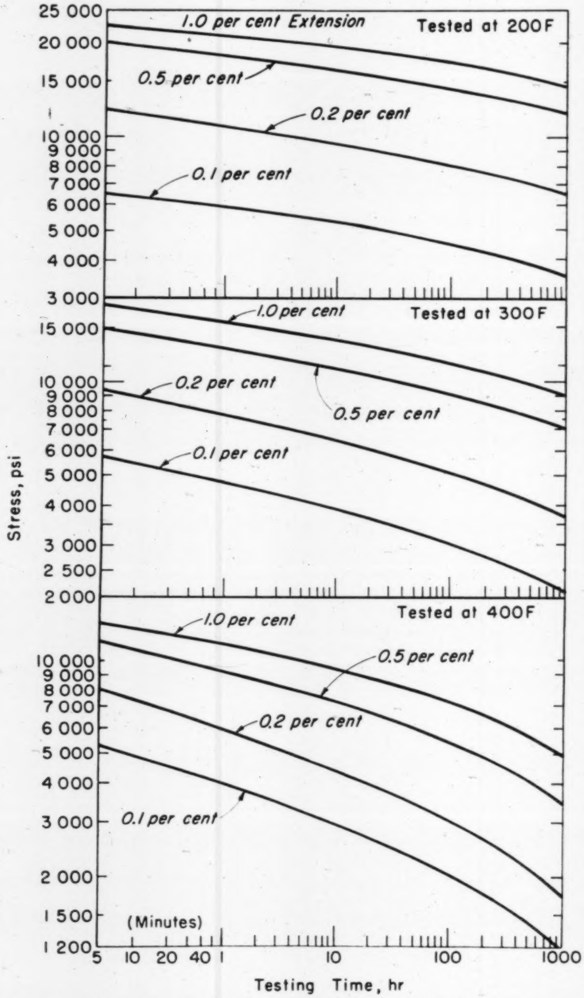

FIG. 6.—Stress for Various Total Extensions at 200, 300, and 400 F. Separately cast test bars of ZK51A-T5 alloy.

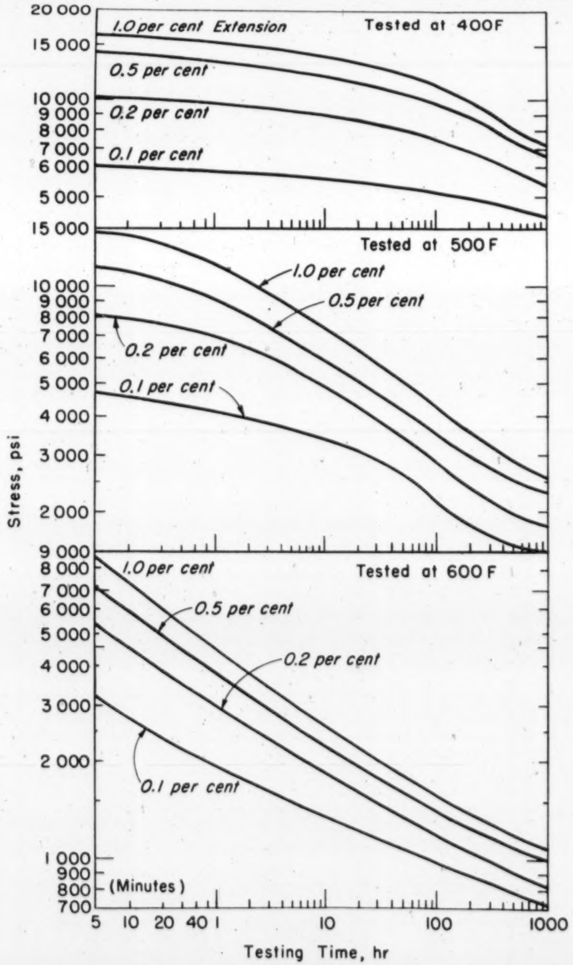

FIG. 7.—Stress for Various Total Extensions at 400, 500, and 600 F. Separately cast test bars of EK30A-T6 alloy.

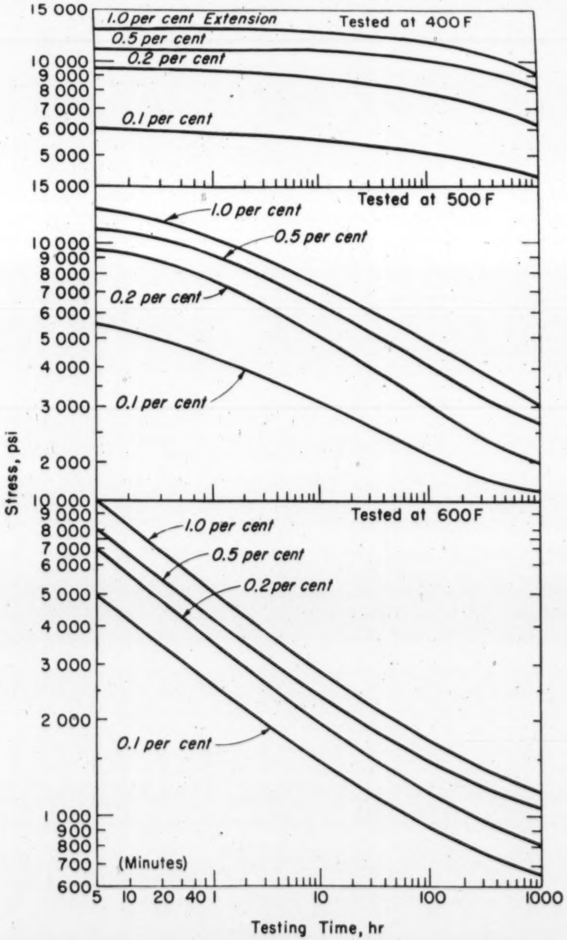

FIG. 8.—Stress for Various Total Extensions at 400, 500, and 600 F. Separately cast test bars of EZ33A-T5 alloy.

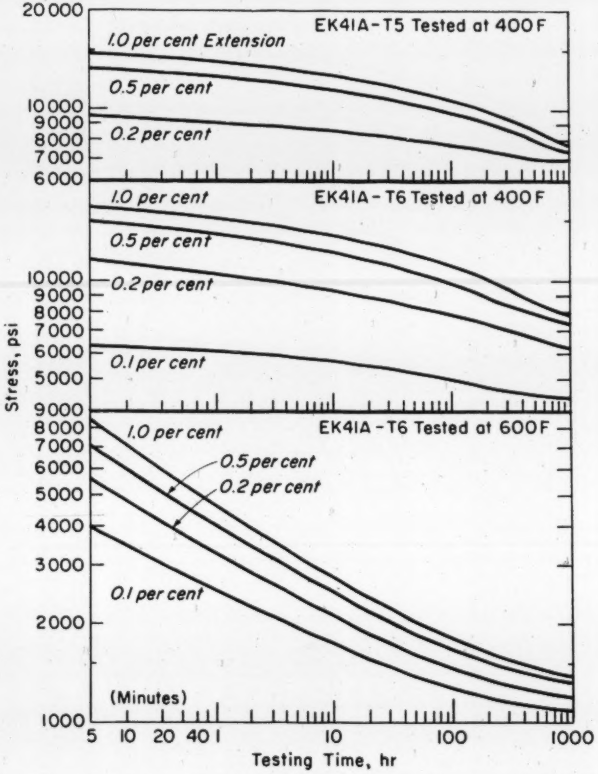

FIG. 9.—Stress for Various Total Extensions at 400 and 600 F. Separately, cast test bars of EK41A-T5 and EK 41A-T6 Alloys.

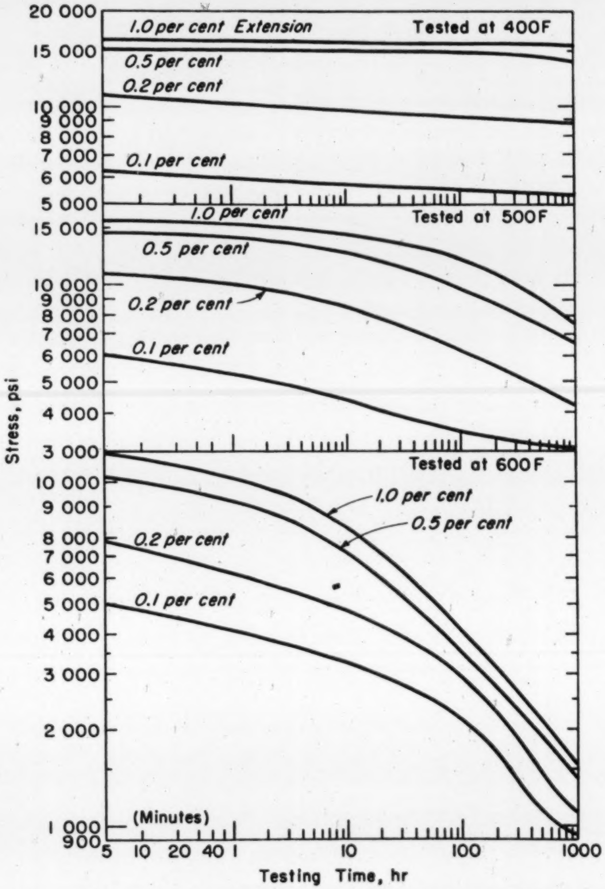

FIG. 10.—Stress for Various Total Extensions at 400, 500, and 600 F. Separately cast test bars of HK31XA-T6 alloy.

systems of alloys have over AZ92A-T6 and ZK51A-T5 at such temperatures.

Although ZK51A-T5 and AZ92A-T6 are comparable at 200 F, the magnesium-zinc-zirconium alloy has some real advantages at 300 and 400 F. Small differences can be seen among the several magnesium - rare earth metal - zirconium alloys. However, due to the known scatter of data characteristic of creep tests (**14**), it is concluded that these alloys cannot be distinguished from each other by this type of test at any of the testing temperatures. There are, however, indications that at 400 F and the higher extensions EK30A-T6 is somewhat inferior to the other rare-earth alloys.

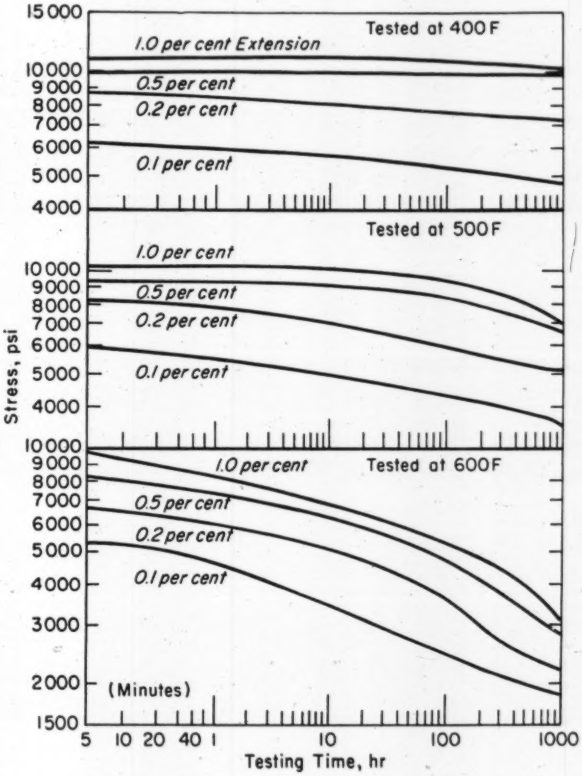

FIG. 11.—Stress for Various Total Extensions at 400, 500, and 600 F. Separately cast test bars of HZ32XA-T5 alloy.

The two magnesium-thorium-zirconium alloys are definitely different, as can be seen by comparing Figs. 10 and 11. In choosing either HK31XA-T6 or HZ32XA-T5, the allowable extension of the part under consideration as well as the operating temperature and time must be considered. At the lower temperatures, shorter times, and larger extensions, HK31XA-T6 alloy is better, while under the reverse conditions of temperature and time, HZ32XA-T5 is better. Thus, the addition of zinc to HK31XA impairs its short-time tensile and creep properties at elevated temperatures.

TABLE III.—EFFECT OF EXPOSURE AT ELEVATED TEMPERATURES ON THE 100-HR CREEP LIMITS OF MAGNESIUM - RARE EARTH METALS - ZINCONIUM ALLOYS.

Separately cast test bars.

Exposure Temperature, deg Fahr	Exposure Time, hr	Testing Temperature, deg Fahr	100-hr Creep Limit, psi[a]					
			EK30A-T6			EZ33A-T5		
			0.1 per cent TE	0.2 per cent TE	0.5 per cent TE	0.1 per cent TE	0.2 per cent TE	0.5 per cent TE
500..............	0	400	5000	6800	9300	5400	8500	10 600
500..............	1	400	4900	6600	9000	5500	8100	10 000
500..............	10	400	4800	6500	7800	5700	7700	9 600
500..............	20	400	4800	6500	7400	5800	7500	9 400
600..............	0	400	5000	6800	9300	5400	8500	10 600
600..............	1	400	4600	6700	8900	5300	7800	9 900
600..............	10	400	3700	5600	7800	5200	7300	9 300
600..............	20	400	3400	5200	7100	5200	7100	9 100

[a] Creep limits given as total extension (TE).

TABLE IV.—EFFECT OF EXPOSURE AT ELEVATED TEMPERATURES ON THE 100-HR CREEP LIMITS OF MAGNESIUM - THORIUM - ZIRCONIUM ALLOYS.

Separately cast test bars.

Exposure Temperature, deg Fahr	Exposure Time, hr	Testing Temperature, deg Fahr	100-hr Creep Limit, psi[a]					
			HK31XA-T6			HZ32XA-T5		
			0.1 per cent TE	0.2 per cent TE	0.5 per cent TE	0.1 per cent TE	0.2 per cent TE	0.5 per cent TE
500..............	0	400	8600	10 600	14 500	5700	6800	8500
500..............	1	400	7700	10 400	14 100	5400	6900	8600
500..............	10	400	7000	10 200	13 600	5100	7000	8800
500..............	20	400	6900	10 100	13 500	5100	7000	8900
500..............	100	400	6400	9 700	13 200	4900	7100	9000
600..............	0	400	8600	10 600	14 500	5700	6800	8500
600..............	1	400	6800	9 500	13 700	5500	7000	8700
600..............	10	400	5500	8 200	12 200	5300	7200	9000
600..............	20	400	5200	7 800	11 700	5300	7200	9100
600..............	100	400	4500	6 800	10 000	5200	7400	9200
650..............	0	400	8600	10 600	14 500	5700	6800	8500
650..............	1	400	6900	9 200	13 300	5400	7200	9200
650..............	10	400	5100	7 100	9 600	5100	7700	9900
700..............	0	400	8600	10 600	14 500	5700	6800	8500
700..............	1	400	6300	8 700	12 200	5400	7000	8800
700..............	4	400	4900	7 600	10 000	5300	7200	9000
600..............	0	500	5100	6 900	10 100			
600..............	1	500	5100	6 900	9 600			
600..............	10	500	5100	6 600	8 500			
600..............	20	500	5000	6 400	8 200			
600..............	100	500	4400	5 600	7 000			
700..............	0	600	2400	3 400	4 300	2800	3700	4700
700..............	1	600	1900	2 500	3 000	2700	3800	5000
700..............	4	600	1600	2 000	2 500	2600	3800	5100

[a] Creep limits given as total extension (TE).

EFFECT OF EXPOSURE AT ELEVATED TEMPERATURES ON 100-HR CREEP PROPERTIES

Efforts to simulate conditions of actual operations by means of laboratory tests are the subject of many investigations. In most applications operating at elevated temperatures, conditions of stress and temperature vary within a given run, although the exact cycle in most parts is not known. The Dow Chemical Co.'s creep machines are not equipped to perform tests under conditions of cyclic stress and temperature. As an approach to this problem, the author has evaluated the effect of exposure at various temperatures on the creep resistance at a given temperature. The effect of cyclic stressing remains for future investigations.

The effect of varying times of exposure on the 100-hr creep limits of two magnesium - rare earth metal - zirconium and two magnesium-thorium-zirconium alloys was determined at several exposure and testing temperatures. The results for the shorter time exposures can be found in Tables III and IV, while Figs. 12 to 15 show the effect of 1000-hr exposure on the 100-hr creep limits of EK30A-T6, EZ33A-T5, HK31XA-T6, and HZ32XA-T5 alloys exposed at 400, 500, and 600 F and tested at the exposure temperature. The creep parameter reported is, again, total extension.

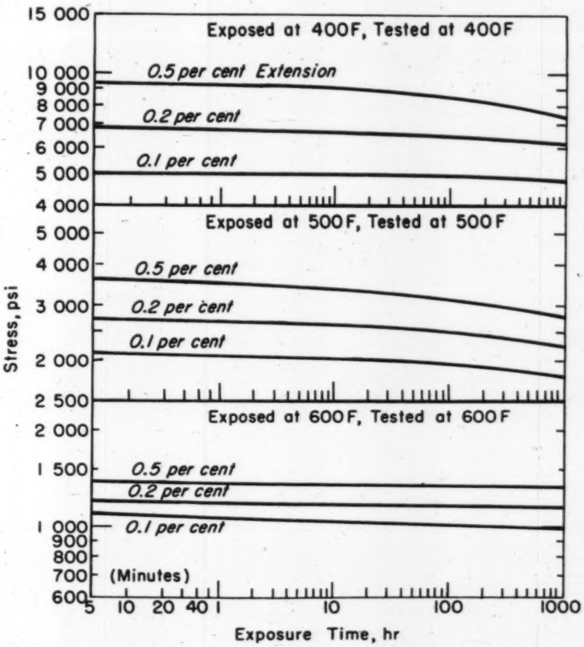

FIG. 12.—Effect of Exposure at Elevated Temperatures on the 100-hr Creep Limits of EK30A-T6 Alloy. Separately cast test bars.

These results are similar to those obtained by tension testing in that the zinc-containing alloys retain higher creep resistance after exposure to elevated temperature than do the zinc-free alloys. The superiority of HK31XA over HZ32XA is apparent at the lower temperatures, however. Even taking the wide scatter characteristic of creep data

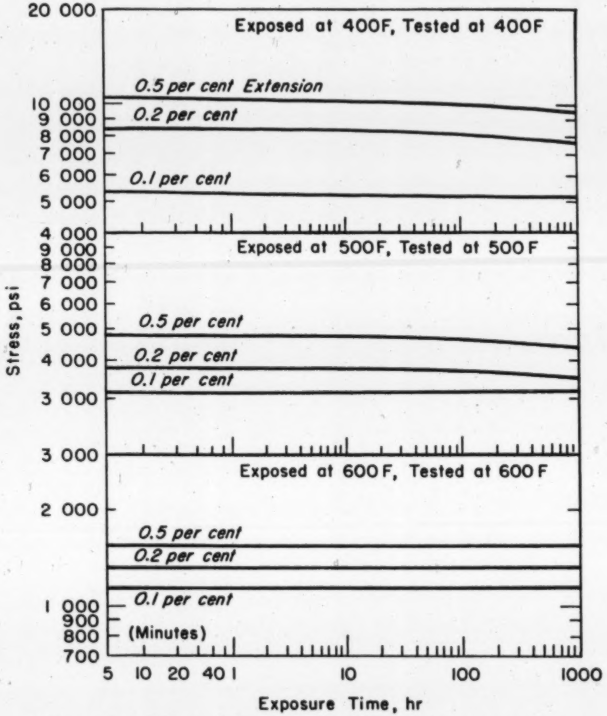

FIG. 13.—Effect of Exposure at Elevated Temperatures on the 100-hr Creep Limits of EZ33A-T5 Alloy. Separately cast test bars.

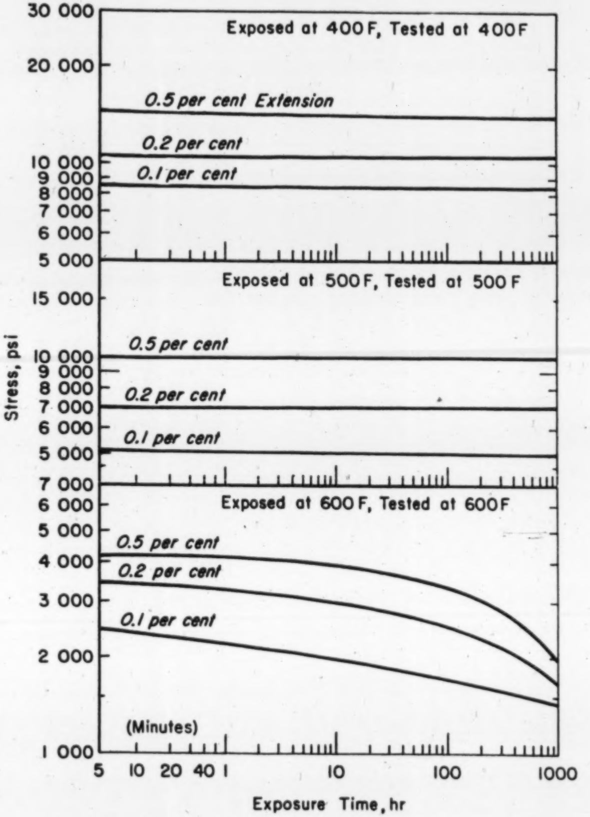

FIG. 14.—Effect of Exposure at Elevated Temperatures on the 100-hr Creep Limits of HK31XA-T6 Alloy. Separately cast test bars.

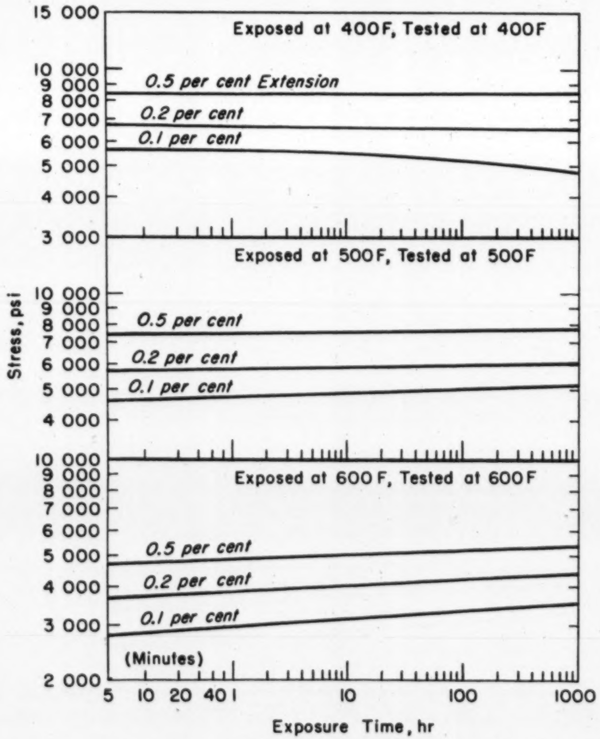

FIG. 15.—Effect of Exposure at Elevated Temperatures on the 100-hr Creep Limits of HZ32XA-T5 Alloy. Separately cast test bars.

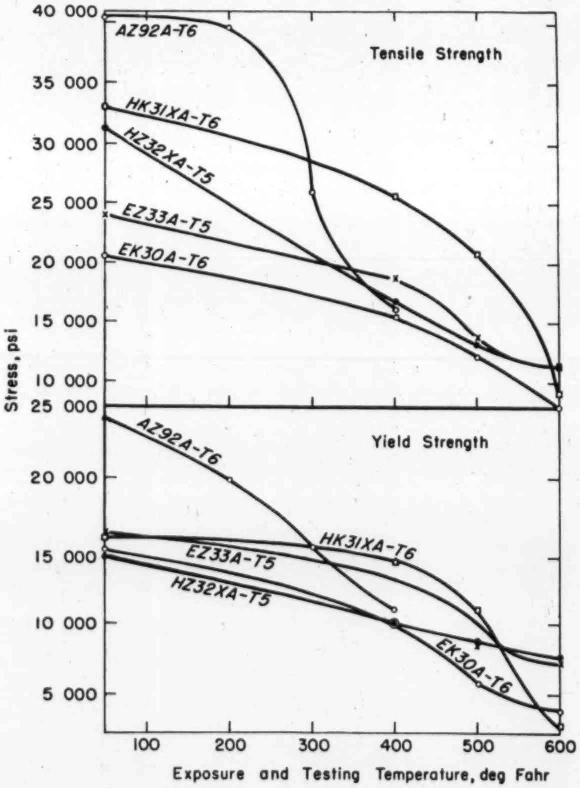

FIG. 16.—Tensile and Yield Strength at Temperature After 1000-hr Exposure at That Temperature. Separately cast test bars.

into account, the trends shown in these several comparisons are significant.

SUMMARY

As discussed in earlier papers, the operating conditions of a part must be known before an attempt is made to select the material for this part. These conditions are the time and temperature of operation as well as the magnitude of stress. These data should be given for at least maximum and normal conditions. If these factors are known along with the allowable deformation, reference to the results presented in this paper should aid the design engineer in choosing a composition for the part.

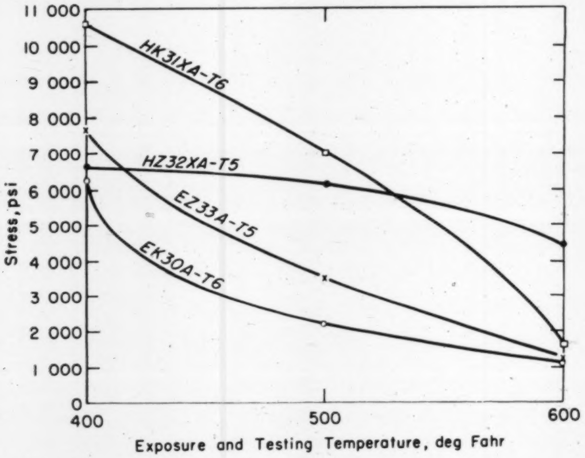

FIG. 17.—Stress for 0.2 per cent Total Extension After 1000-hr Exposure at Testing Temperature, 100-hr Creep Tests. Separately cast test bars.

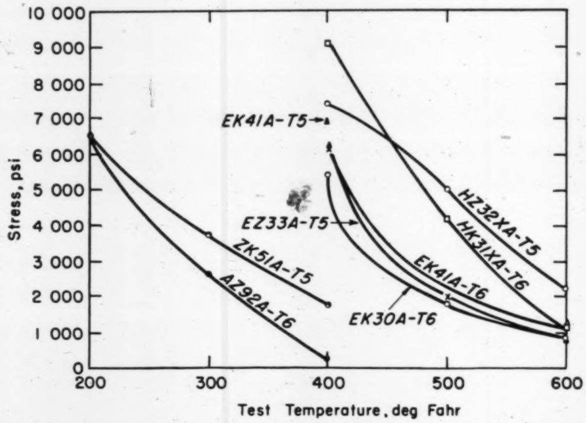

FIG. 18.—Stress for 0.2 per cent Total Extension in 1000 hr for the Various Test Temperatures. Separately cast test bars.

A general comparison of the several alloys reported can be found in the summary results of Figs. 16, 17, and 18. It should be emphasized that these figures present only general alloy comparisons. The material presented earlier in the paper is more useful for design purpose than are these last three figures. Furthermore, it should be recognized that the data in this paper are based on a few batches of metal having an analysis approximately that of nominal composition.

REFERENCES

(1) K. E. Nelson, *Transactions*, Am. Inst. Mining and Metallurgical Engrs. (1953); *Journal of Metals*, Vol. 5, November, 1953, p. 1493.

(2) J. C. McDonald, *Proceedings*, Am. Soc. Testing Mats., Vol. 48, p. 737 (1948).

(3) K. E. Nelson, *Transactions*, Am. Foundrymen's Soc., Vol. 61, p. 315 (1953).

(4) K. E. Nelson, discussion of paper by C. J. P. Ball *et al.*, *Transactions*, Am. Inst. Mining and Metallurgical Engrs. (1953); paper also published in *Journal of Metals*, Vol. 5, July, 1953, p. 924.

(5) T. E. Leontis, *Transactions*, Am. Inst. Mining and Metallurgical Engrs., Vol. 180, p. 287 (1948).

(6) J. F. Hildebrand and F. P. Strieter, *Transactions*, Am. Foundrymen's Soc., Vol. 60, p. 595 (1952).

(7) J. W. Meier and M. W. Martinson, *Transactions*, Am. Foundrymen's Soc., Vol. 58, p. 742 (1950).

(8) J. W. Meier, *Transactions*, Am. Foundrymen's Soc., Vol. 61, p. 719 (1953).

(9) C. J. P. Ball, *Metallurgia*, Vol. 35, p. 125 (1947).

(10) H. J. Millward, *American Foundryman*, Vol. 20, No. 3, p. 44 (1951).

(11) H. Baker, "Tensile and Creep Properties at Elevated Temperatures of Some Magnesium-Base Wrought Alloys," *Proceedings*, Am. Soc. Testing Mats., Vol. 54, p. 1068 (1954).

(12) C. E. Nelson, *Transactions*, Am. Inst. Mining and Metallurgical Engrs., Vol. 159, p. 392 (1944).

(13) K. E. Nelson and F. P. Strieter, *Transactions*, Am. Foundrymen's Soc., Vol. 58, p. 400 (1950).

(14) K. E. Nelson and F. P. Strieter, *Transactions*, Am. Foundrymen's Soc., Vol. 59, p. 532 (1951).

(15) K. E. Nelson, *Transactions*, Am. Foundrymen's Soc., Vol. 61, p. 315 (1953).

(16) J. C. McDonald, *Light Metals Age*, Vol. 9, No. 11, December, 1951, p. 12.

(17) A. A. Moore and J. C. McDonald, *Proceedings*, Am. Soc. Testing Mats., Vol. 46, p. 970 (1946).

(18) T. E. Leontis and J. P. Murphy, *Transactions*, Am. Inst. Mining and Metallurgical Engrs., Vol. 166, p. 295 (1946).

STATISTICAL EVALUATION OF THE CREEP-RUPTURE PROPERTIES OF FOUR HEAT-RESISTANT ALLOYS IN SHEET FORM*†

BY A. I. RUSH[1] AND J. W. FREEMAN[1]

SYNOPSIS

Stress-rupture tests were conducted on ten heats each of four alloys, Type 321, Type 347, N155, and Inconel X. The ten heats represented material from several suppliers when possible and were tested at three temperatures between 1200 and 1650 F for times up to 80 or 300 hr, depending upon the temperature and material. Total deformation strengths were determined for elongations of 0.2, 0.5, 1.0, and 2.0 per cent for time periods of 1, 5, 20, 80, and 300 hr, insofar as the data obtained from the rupture tests permitted.

Duplicate room-temperature tension tests were conducted on specimens selected from each heat to establish the variation in tensile properties within the sheet as well as sheet-to-sheet variations.

All of the stress-rupture, total deformation, and tension test data were examined statistically to establish average values and the standard deviations where sufficient data were available.

No effort has been made to explain heat-to-heat variations in strength on the basis of metallurgical variables or to correlate tensile properties with stress-rupture properties.

The rapid increase in the use of materials at increasingly higher temperatures presents the design engineer with the problem of establishing reliable new design values. Each material is expected to have a range in properties which reflects normal production variations in chemical composition, processing conditions, and heat treatment. Thus, sound design values require establishment of the ranges in properties normally to be expected under commercial production conditions.

This paper presents the results of a statistical evaluation of the ranges in creep-rupture properties of four sheet alloys as commercially produced. The data established were those primarily required by the aviation industry for very high temperature sheet applications. The alloys were 18 Cr-8 Ni (Ti) (AISI 321), 18 Cr-8 Ni (Cb-Ta) (AISI 347), N155 (AMS 5532), and Inconel X

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† This paper is based on the results of an investigation sponsored by the Aviation Panel of the ASME-ASTM Joint Committee on the Effect of Temperature on the Properties of Metals and was carried out at the Engineering Research Institute of the University of Michigan.

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TABLE I.—DESCRIPTION OF 18 Cr-8 Ni (Ti) (TYPE 321) SHEET MATERIALS.

Supplier	Heat No.	Chemical Composition, per cent										Gage, in.
		Carbon	Manganese	Phosphorus	Sulfur	Silicon	Copper	Nickel	Chromium	Titanium	Molybdenum	
B.........	R10356	0.042	1.44	0.027	0.009	0.57	...	9.49	17.41	0.65	...	0.040
B.........	E02326	0.053	1.73	0.026	0.012	0.58	...	9.76	18.01	0.49	...	0.040
D.........	E1880[a]	...	...	...	...	...	...	...	...	...	...	0.040
C.........	X25677	0.07	1.65	0.022	0.006	0.58	...	10.43	17.84	0.55	...	0.040
D.........	E41024[a]	...	...	...	...	...	...	...	...	...	...	0.040
A.........	627967	0.078	1.33	0.025	0.009	0.34	0.27	9.98	17.75	0.57	...	0.048
B.........	R30409	0.035	1.50	0.030	0.015	0.66	...	9.36	17.72	0.50	...	0.040
D.........	E1869[a]	...	...	...	...	...	...	...	...	...	...	0.040
C.........	X46099	0.06	1.56	0.021	0.005	0.84	0.24	10.21	17.76	0.49	0.13	0.035 to 0.045
C.........	X13043	0.05	1.43	0.029	0.005	0.94	0.24	10.56	17.56	0.46	0.15	0.035 to 0.045

[a] Surface finish and composition not reported; all others reported to have 2-D finish.

TABLE II.—DESCRIPTION OF 18 Cr-8 Ni (Cb-Ta) (TYPE 347) SHEET MATERIALS.

Supplier	Heat No.	Chemical Composition, per cent												Gage, in.
		Carbon	Manganese	Phosphorus	Sulfur	Silicon	Copper	Nickel	Chromium	Columbium + Tantalum	Tantalum	Columbium	Molybdenum	
A...	620809	0.08	1.89	0.026	0.010	0.80	0.14	10.42	17.66	0.96	...	...	...	0.040 to 0.050
A...	620813	0.076	1.78	0.024	0.010	0.53	0.16	10.34	17.92	0.77	...	...	...	0.040 to 0.050
A...	636862	0.064	1.89	0.025	0.010	0.50	0.20	10.76	17.60	0.71	...	...	...	0.040 to 0.050
D..	E40470	0.07	1.68	0.018	0.017	0.80	0.10	10.44	17.55	...	0.25	0.57	0.12	0.040
D..	E41286	0.06	1.52	0.033	0.021	0.57	0.16	10.37	17.55	...	0.13	0.67	0.14	0.040
D..	E41887	0.05	1.67	0.028	0.019	0.98	0.18	10.36	17.69	...	0.13	0.62	0.24	0.040
D..	E41737	0.05	1.88	0.024	0.016	0.62	0.15	10.33	17.68	...	0.10	0.63	0.18	0.031
C...	7X7935	0.07	1.40	0.030	0.018	0.45	0.24	10.29	18.49	...	...	0.76	0.15	0.035 to 0.045
C...	X25788	0.07	1.83	0.016	0.005	0.73	0.26	11.91	17.68	...	...	0.94	...	0.035 to 0.045
C...	3X0005[a]	0.04	1.58	0.018	0.020	0.39	0.06	11.40	18.24	...	...	0.62	0.02	0.035 to 0.045

[a] 2-B finish; all others 2-D finish.

(AMS 5542). Ten sheets of each alloy from different heats were included. Attempts were made to obtain samples from several producers. Tests were carried out to establish the stresses for rupture according to the following schedule:

Temperature, deg Fahr	Rupture Time, hr			Type Alloys
1200.....	20	80	300	321, 347, Inconel X
1350.....	20	80	300	321, 347, Inconel X, N155
1500.....	5	20	80	321, 347
1500.....	20	80	300	Inconel X, N155
1650.....	5	20	80	N155

In addition, the creep curves from the rupture tests were analyzed for deformations of 0.2, 0.5, 1.0, and 2.0 per cent as a function of time.

The investigation was sponsored by the ASME-ASTM Joint Committee on the Effect of Temperature on the Properties of Metals. The program was formulated and supervised by the Aviation Panel of the Joint Committee.

Description of Test Material

The alloys were all furnished gratuitously by several producers as commercial material produced to the following specifications:

Material	Specification	Condition	Finish
AISI 321............	MIL-S-6721, composition Ti	Annealed and pickled	Commercial 2-D
AISI 347...........	MIL-S-6721, composition Cb-Ta	Annealed and pickled	Commercial 2-D
N155...............	AMS 5532	Per AMS 5532	Per AMS 5532
Inconel X...........	AMS 5542	Heat treated and aged	Per AMS 5532

The heat numbers, number of sources, chemical composition, and other descriptive material supplied by the manufacturers are given in Tables I to IV.

PROCEDURE

The general procedure was to sample each sheet according to a scheme designed to avoid misleading results from possible variations within the individual sheets. Tension tests were run at room temperature to show normal variation in properties from sheet to sheet and within each sheet. Rupture tests were made by estimating the stress required to give rupture at the intermediate time periods and then adjusting the stresses in subsequent tests to give rupture in the specified time periods. Creep curves, including stress-strain curve during loading, were established for the rupture tests.

No means were available for reliably fastening extensometers to the gage lengths of the specimens during the rupture tests. For this reason, they were fastened to the shoulders of the specimens. This necessitated considerable work to establish reliable means of correcting for strain in the fillets and shoulders of the specimens.

A good deal of care was taken to follow exact procedures as agreed upon with representatives of the Aviation Panel. Because these may be of considerable influence on the results, they are presented in some detail in the following sections.

Sampling:

All sheets were divided into three equal sections taken perpendicular to the direction of rolling, and at least one

TABLE III.—DESCRIPTION OF INCONEL X (AMS 5542) SHEET MATERIALS.

Supplier	Heat No.	Chemical Composition, per cent											Gage, in.
		Carbon	Manganese	Sulfur	Silicon	Copper	Nickel	Chromium	Aluminum	Titanium	Columbium	Iron	
E.........	Y4474X	0.05	0.57	0.007	0.35	0.07	73.67	14.70	0.84	2.49	0.53	6.70	0.043
E.........	Y3166X	0.04	0.54	0.007	0.36	0.03	73.07	14.73	0.80	2.38	1.02	6.94	0.043
E.........	Y4602X	0.04	0.57	0.007	0.44	0.06	72.56	14.88	0.90	2.69	0.90	6.97	0.043
E.........	Y4860X	0.03	0.50	0.007	0.30	0.02	73.46	14.66	0.88	2.59	0.83	6.70	0.043
E.........	Y4512X	0.04	0.57	0.007	0.33	0.02	73.16	14.78	0.79	2.44	1.03	6.81	0.043
E.........	Y4511X	0.03	0.56	0.007	0.31	0.02	73.25	14.71	0.77	2.35	1.09	6.88	0.043
E.........	Y4847X	0.03	0.55	0.007	0.37	0.04	73.34	15.14	0.76	2.39	0.77	6.68	0.043
E.........	Y4984X	0.03	0.54	0.007	0.39	0.16	72.96	14.93	0.85	2.57	0.88	6.66	0.043
E.........	253X	0.03	0.75	0.007	0.31	0.05	72.24	15.31	0.78	2.65	0.83	7.02	0.045

specimen was obtained from each section for each stress-rupture testing temperature.

Two tension specimens were obtained from each sheet, one from the outside edge of the sheet and the other from the center.

All specimens were taken with the testing direction transverse to the direction of rolling.

TABLE IV.—DESCRIPTION OF N155 (AMS 5532) SHEET MATERIALS.

Supplier	Heat No.	Chemical Composition, per cent														Gage, in.
		Carbon	Manganese	Phosphorus	Sulfur	Silicon	Nickel	Chromium	Cobalt	Columbium	Tantalum	Columbium + Tantalum	Tungsten	Molybdenum	Nitrogen	
F.....	M624	0.11	1.45	0.028	0.013	0.41	20.08	21.20	20.05	...	...	0.84	2.40	3.08	0.12	0.044
F.....	M206	0.08	1.32	0.022	0.020	0.50	19.72	21.52	19.81	0.66	0.23	0.89	2.37	3.22	0.12	0.042
F.....	M208	0.10	1.50	0.023	0.018	0.50	19.26	21.66	19.37	0.80	0.25	1.05	2.34	3.17	0.14	0.042
F.....	M207	0.10	1.47	0.021	0.015	0.50	19.88	21.49	19.49	0.79	0.23	1.02	2.53	3.28	0.11	0.042
F.....	M733	0.10	1.39	0.020	0.015	0.53	20.18	20.83	20.17	...	...	0.81	2.46	2.98	0.11	0.050
F.....	M737	0.12	1.69	0.030	0.015	0.46	20.36	21.17	19.52	...	...	0.81	2.25	3.06	0.11	0.050
F.....	M732	0.11	1.27	0.026	0.015	0.53	20.04	21.08	20.26	...	...	0.82	2.38	2.96	0.10	0.050
F.....	M731	0.13	1.36	0.021	0.014	0.49	19.75	20.78	19.38	...	...	0.79	2.42	2.84	0.10	0.050
F.....	M726	0.12	1.62	0.020	0.012	0.50	19.37	21.74	20.25	...	...	0.81	2.43	3.08	0.11	0.050
F.....	M730	0.10	1.52	0.020	0.016	0.42	20.12	20.78	19.05	...	...	0.76	2.52	2.96	0.10	0.050

Specimen Design:

The specimens used were 22 in. long and 1 in. wide in the shoulder area. The reduced section was 0.500 in. wide by 2.25 in. long and was located in the center of the 22-in. length. The fillet between the reduced section and shoulder area had a 1-in. radius. Holes $\frac{5}{32}$ in. in diameter were drilled in the shoulder areas for the attachment of extensometers.

Machining:

The same machining procedure was employed for all specimens. The specimens were milled to not less than $\frac{1}{32}$ in. of finish size on each side and then ground to finish size. Final grinding was done in the longitudinal direction, using a 46-grit, white borlon, medium hard wheel with a vitrified bond (Simond's Wheel WA 46-K5-V1).

Testing Procedure:

Tension Testing.—Duplicate tension tests were run. All tests were conducted with a free head-speed of 0.05 in. per min, and strain data were obtained by means of an optical extensometer system. The stress-strain curves plotted from this data were used to establish yield strengths.

Stress-Rupture Testing.—All stress-rupture tests were conducted in single units of the dead weight-beam loaded type, except when low stresses required the use of a direct load.

The following procedure was used to bring the test specimens to temperature:

1. Specimens were set up in the testing units and the heat turned on at 4:00 p m in order to bring the temperature within 50 F of the desired temperature by 5:00 p m.

2. The specimens were allowed to stand overnight and the temperature raised to the test temperature between 8:00 and 9:00 a m the next day.

3. Final temperature adjustments were made so that the stress could be applied at 1:00 p m.

4. The temperature distribution along the length of the specimen and the temperature variations with time were within the limits of ASTM Recommended Practice E 85.[2]

Time-elongation data were obtained by means of extensometers. Collars were fixed on the upper and lower shoulders of the specimens by means of pins inserted through holes drilled in the specimen shoulder. Extension rods were attached to the collars and extended out of the furnace. Rollers carrying a mirror were inserted between each pair

TABLE V.—ROOM TEMPERATURE TENSILE DATA FROM TYPE 321, TYPE 347, INCONEL X, AND N155 SHEET MATERIAL.

Properties	Material			
	Type 321[a]	Type 347[b]	Inconel X[b]	N155[a]
TENSILE STRENGTH, PSI				
Range	81 500–92 800	87 500–102 000	156 500–185 800	116 600–121 200
Maximum difference for one heat	4 000	3 000	3 500	2 300
Average	85 550	94 400	174 000	119 050
Standard deviation	3 380	3 840	7 900	1 320
0.1 PER CENT OFFSET YIELD STRENGTH, PSI				
Range	27 500–43 500	32 500–51 000	99 500–132 500	47 900–58 000
Maximum difference for one heat	4 500	10 000	5 500	6 200
Average	32 900	39 800	118 000	52 250
Standard deviation	3 960	4 490	8 550	2 340
0.2 PER CENT OFFSET YIELD STRENGTH, PSI				
Range	30 000–45 500	35 500–54 000	102 000–136 000	55 400–64 500
Maximum difference for one heat	3 500	8 500	6 000	5 000
Average	36 000	43 300	121 500	59 550
Standard deviation	3 910	4 540	8 725	2 230
PROPORTIONAL LIMIT, PSI				
Range	14 000–22 000	14 000–28 000	76 500–110 000	17 000–29 000
Maximum difference for one heat	7 500	9 000	7 000	9 000
Average	16 300	19 800	91 100	21 575
Standard deviation	2 440	3 850	8 890	3 850
ELONGATION, PER CENT IN 2 IN.				
Range	51.0–74.7	51.5–64.5	23.5–32.0	51.5–57.5
Maximum difference for one heat	5.4	5.5	5.0	3.0
Average	64.4	59.1	28.0	53.8
Standard deviation	5.65	4.74	2.86	1.47

[a] Based on values from 10 heats.
[b] Based on values from 9 heats.

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[2] Tentative Recommended Practice for Conducting Time-for-Rupture Tension Tests of Metallic Materials (E 85 – 50 T), 1952 Book of ASTM Standards, Part 1, p. 1517.

TABLE VI.—RUPTURE AND TOTAL DEFORMATION STRENGTHS OF TEN HEATS OF TYPE 321 SHEET MATERIAL AT 1200, 1350, AND 1500 F.

Heat No.	Stress for Rupture or Indicated Total Deformation in the Specified Time Period										
	1200 F			1350 F				1500 F			
	20 hr	80 hr	300 hr	5 hr	20 hr	80 hr	300 hr	1 hr	5 hr	20 hr	80 hr
RUPTURE STRENGTH, PSI											
R10356..	33 500	28 500	22 500	...	19 000	15 000	11 500	...	12 000	10 000	7 100
E02326..	34 000	27 500	22 500	...	17 500	13 500	10 700	...	13 000	9 600	6 600
E1880...	33 500	28 000	23 500	...	21 500	16 500	13 000	...	14 800	11 200	8 500
X25677..	33 500	29 500	23 500	...	20 500	16 000	12 500	...	13 200	11 500	6 700
E41024..	33 500	31 000	24 500	...	22 000	18 500	14 600	...	13 600	11 000	8 800
627967...	32 000	27 500	22 500	...	19 000	16 000	13 000	...	14 000	10 800	8 200
R30409..	34 500	27 500	22 000	...	20 500	15 500	11 300	...	12 000	10 300	7 500
E1869...	36 000	29 500	24 000	...	21 000	17 500	13 500	...	15 500	12 500	7 800
X46099..	31 000	26 000	21 000	...	18 000	14 300	11 500	...	13 500	9 900	7 200
X13043..	29 500	25 000	19 500	...	17 500	14 000	10 500	...	12 500	9 500	7 200
2.0 PER CENT DEFORMATION STRENGTH, PSI											
R10356..	29 500	24 000	19 000	...	16 000	12 500	9 700	12 200	10 000	7 400	5 400
E02326..	28 000	24 500	20 000	...	16 300	11 700	8 600	14 500	10 000	7 400	5 700
E1880...	25 000	23 500	22 000	21 500	17 500	14 200	11 000	15 200	11 700	8 800	6 700
X25677..	28 500	25 000	21 000	20 500	17 000	12 800	9 600	12 200	9 800	7 600	...
E41024..	26 500	25 500	21 000	21 500	20 000	17 000	14 000	13 500	12 000	9 800	7 900
627967..	29 000	24 000	20 000	...	17 500	14 500	12 000	14 000	11 300	9 300	7 800
R30409..	27 500	24 000	19 500	...	16 500	13 000	10 200	11 500	10 200	8 300	(4 600)
E1869...	29 500	27 000	22 000	...	18 500	15 500	(12 000)	...	12 500	10 500	(6 600)
X46099..	25 000	21 000	18 000	17 500	14 000	11 500	(9 600)	12 000	9 000	7 100	...
X13043..	23 500	19 500	16 000	...	14 500	10 000	...	...	9 200	6 800	...
1.0 PER CENT DEFORMATION STRENGTH, PSI											
R10356..	24 000	22 500	...	18 000	14 000	11 000	9 000	11 500	8 800	6 200	...
E02326..	25 500	23 000	...	...	14 500	10 500	(7 600)	12 500	8 800	6 400	...
E1880...	24 000	22 500	...	19 000	16 500	12 500	(9 300)	14 000	10 300	7 800	5 800
X25677..	25 500	23 000	...	18 500	15 500	12 000	(9 000)	11 300	9 000	6 700	...
E41024..	...	...	...	19 500	18 500	16 000	13 000	12 500	11 200	9 000	7 200
627967..	26 500	22 500	...	...	15 500	13 500	(11 500)	12 500	10 100	8 400	7 000
R30409..	24 500	21 500	...	17 000	15 000	11 500	(9 000)	11 000	9 800	6 800	...
E1869...	26 000	24 000	...	...	17 000	14 000	...	14 200	11 700	9 000	...
X46099..	23 000	20 000	...	15 500	12 500	10 000	...	10 400	8 000	6 400	...
X13043..	22 000	17 500	...	16 500	12 000	...	...	11 000	7 600	5 600	...
0.5 PER CENT DEFORMATION STRENGTH, PSI											
R10356..	23 000	...	...	16 000	12 000	9 500	...	10 500	7 400	(5 600)	...
E02326..	22 500	20 500	...	...	13 000	8 700	...	11 000	7 400	(5 300)	...
E1880...	22 500	21 000	...	17 500	14 500	(9 600)	...	12 300	8 800	6 600	...
X25677..	23 000	(20 000)	...	17 000	14 500	(9 800)	...	9 800	7 700	...	...
E41024..	...	...	...	18 000	17 000	14 000	...	12 000	10 300	8 100	...
627967..	25 000	21 000	...	16 000	14 300	12 500	...	11 500	9 100	7 500	...
R30409..	...	...	...	16 000	14 000	(9 600)	...	10 500	9 300	(5 400)	...
E1869...	...	...	...	19 500	15 500	12 500	...	12 800	10 500	(7 200)	...
X46099..	21 500	...	...	13 500	11 000	...	...	8 700	7 000	(5 700)	...
X13043..	19 000	...	...	14 000	9 200	...	...	9 500	6 300	...	...
0.2 PER CENT DEFORMATION STRENGTH, PSI											
R10356..	...	...	...	12 500	10 000	...	...	8 300	6 000	...	...
E02326..	...	...	...	13 500	10 500	...	...	8 200	5 500	...	...
E1880...	...	...	...	14 000	10 500	...	...	10 500	6 600	...	...
X25677..	...	...	...	15 000	12 000	...	...	8 700	6 200	...	...
E41024..	...	...	...	17 000	16 000	...	...	10 500	8 200	...	...
627967..	23 000	...	...	14 500	12 800	...	...	9 000	7 200	...	...
R30409..	...	...	...	15 000	11 000	...	...	9 800	6 300	...	...
E1869...	...	...	...	15 500	12 500	...	...	11 000	8 600	...	...
X46099..	...	...	...	10 300	...	...	...	7 500	6 000	...	...
X13043..	...	...	...	9 600	...	...	...	7 200	...	...	...

NOTE.—Parentheses around strength values indicate extrapolated values.

TABLE VII.—RUPTURE AND TOTAL DEFORMATION STRENGTHS OF TEN HEATS OF TYPE 347 SHEET MATERIAL AT 1200, 1350, AND 1500 F.

Heat No.	Stress for Rupture or Indicated Total Deformation in the Specified Time Period										
	1200 F			1350 F				1500 F			
	20 hr	80 hr	300 hr	5 hr	20 hr	80 hr	300 hr	1 hr	5 hr	20 hr	80 hr
Rupture Strength, psi											
620809....	38 000	32 500	28 000	...	23 000	18 000	14 000	...	13 500	11 500	8 300
620813....	38 500	33 500	29 000	...	23 500	19 000	15 000	...	15 000	11 500	8 300
636862....	38 000	32 000	28 000	...	24 000	18 000	13 500	...	13 000	10 500	7 700
E40470....	36 000	32 000	26 500	...	20 000	17 000	14 000	...	14 200	10 500	9 000
E41286....	37 500	32 000	28 000	...	23 500	19 000	15 500	...	13 500	11 800	9 200
E41887....	42 000	36 000	30 000	...	22 000	18 500	15 000	...	15 000	12 800	9 800
E41737....	36 000	30 000	25 000	...	23 000	18 000	14 000	...	14 000	11 000	8 800
7X7935....	33 000	28 000	21 500	...	20 000	14 500	9 000	...	12 000	9 200	6 000
X25788....	39 000	29 000	22 000	...	17 000	13 500	10 000	...	12 000	8 400	6 000
3X0005....	36 000	31 000	26 000	...	22 000	18 000	14 500	...	(14 000)	12 000	9 000
2.0 per cent Deformation Strength, psi											
620809....	31 000	27 500	...	20 500	19 000	16 000	(12 000)	13 000	11 000	8 400	...
620813....	30 000	29 000	27 000	21 500	20 000	16 500	(13 300)	12 000	9 800	8 200	...
636862....	29 000	26 500	...	21 500	19 500	14 500	(11 000)	13 000	10 600	8 100	...
E40470....	29 500	27 500	...	20 500	17 500	14 500	(12 000)	13 500	10 500	8 500	...
E41286....	30 500	29 000	27 000	23 500	21 500	17 500	14 500	13 500	11 000	9 000	7 600
E41887....	...	29 000	...	21 500	18 500	15 500	(13 000)	15 000	11 000	8 600	...
E41737....	30 000	28 000	24 000	...	21 500	16 000	(12 500)	12 700	10 400	8 600	...
7X7935....	30 500	25 000	(20 000)	...	15 500	10 600	...	...	7 800	...	...
X25788....	30 000	24 000	...	17 000	12 500	...	...	10 000	6 600	4 800	...
3X0005....	27 000	26 000	24 500	21 000	19 000	16 000	13 000	13 000	10 800	9 000	7 700
1.0 per cent Deformation Strength, psi											
620809....	...	...	...	20 000	18 000	14 000	...	12 000	10 000	7 600	...
620813....	...	...	...	19 000	18 000	15 300	...	11 000	9 000	7 500	...
636862....	...	...	...	19 000	17 000	13 500	...	12 000	9 600	7 100	...
E40470....	26 000	...	...	19 000	16 500	13 800	...	12 000	9 600	7 800	...
E41286....	...	...	...	21 000	19 500	16 800	...	12 800	10 200	8 400	...
E41887....	29 500	...	...	19 000	17 000	14 500	...	11 000	8 000	...	...
E41737....	...	25 500	...	...	19 000	14 500	...	11 700	9 700	7 800	...
7X7935....	28 000	23 000	...	19 500	13 000	9 000	...	...	5 600	...	...
X25788....	28 000	22 000	...	14 000	10 500	...	...	7 800	5 300	...	...
3X0005....	...	...	...	20 000	18 000	15 000	...	11 600	9 800	8 400	...
0.5 per cent Deformation Strength, psi											
620809....	...	...	...	19 000	15 500	...	...	11 000	9 000	...	...
620813....	...	...	...	17 500	16 000	...	...	...	8 400	...	...
636862....	...	...	...	17 500	16 000	...	...	10 500	8 700	...	...
E40470....	...	...	...	16 500	15 000	13 000	...	11 000	8 600	...	...
E41286....	...	...	...	19 000	18 000	15 500	...	11 500	9 400	7 800	...
E41887....	...	...	...	17 500	15 500	...	...	9 200	...	...	...
E41737....	...	...	...	19 000	16 500	13 000	...	10 800	9 000	...	...
7X7935....	26 000	21 000	...	16 000	11 000	...	...	8 000	...	...	...
X25788....	26 000	21 000	...	12 000	9 000	...	...	6 200	4 100	...	...
3X0005....	...	...	...	18 000	17 000	14 000	...	10 200	8 600	7 400	...
0.2 per cent Deformation Strength, psi											
620809....	...	...	...	15 500	...	...	...	9 000	7 500	...	...
620813....	...	...	...	16 000	...	...	...	...	7 400	...	...
636862....	...	...	...	14 500	...	...	...	9 000	7 200	...	...
E40470....	...	...	...	14 500	...	...	...	9 400	7 400	...	...
E41286....	...	...	...	17 500	15 000	...	...	9 800	8 000	...	...
E41887....	...	...	...	15 500	...	...	...	...	...	...	...
E41737....	...	...	...	16 000	14 000	...	...	9 000	7 500	...	...
7X7935....	...	...	...	11 000	...	...	...	...	...	...	...
X25788....	20 500	...	...	9 400	...	...	...	4 600	...	...	...
3X0005....	...	...	...	16 000	14 500	...	...	8 500	7 200	...	...

Note.—Parentheses around strength values indicate extrapolated values.

TABLE VIII.—RUPTURE AND TOTAL DEFORMATION STRENGTHS OF NINE HEATS OF INCONEL X SHEET MATERIAL AT 1200, 1350, AND 1500 F.

Heat No.	Stress for Rupture or Indicated Total Deformation in the Specified Time Period								
	1200 F			1350 F			1500 F		
	20 hr	80 hr	300 hr	20 hr	80 hr	300 hr	20 hr	80 hr	300 hr
	Rupture Strength, psi								
Y4474X	68 000	55 000	45 500	49 000	38 500	30 000	31 500	25 000	20 000
Y3166X	64 000	53 000	44 000	41 000	33 000	27 000	27 000	20 000	15 000
Y4602X	80 000	68 000	58 000	50 000	42 000	32 000	28 500	19 300	13 000
Y4860X	57 000	47 500	40 000	42 500	34 500	28 000	32 000	23 500	16 500
Y4512X	68 000	58 500	50 000	47 000	38 000	32 000	29 500	21 200	15 500
Y4511X	69 000	64 000	60 000	48 500	39 500	32 500	26 000	19 000	14 000
Y4847X	66 000	57 500	50 000	45 000	37 000	30 500	27 500	20 000	14 500
Y4984X	78 000	67 000	58 000	54 000	42 500	33 000	27 500	20 000	15 000
253X	74 000	65 000	57 000	54 000	42 500	33 000	29 000	21 000	15 000
	2.0 per cent Deformation Strength, psi								
Y4474X	...	...	...	...	...	...	...	...	...
Y3166X	...	...	...	...	...	...	...	...	...
Y4602X	...	...	...	...	...	...	27 500	17 500	11 500
Y4860X	...	...	...	...	...	...	...	...	...
Y4512X	...	...	...	...	...	...	29 000	20 500	14 800
Y4511X	...	...	...	...	...	...	...	18 000	13 600
Y4847X	...	...	...	...	...	...	25 500	19 000	13 500
Y4984X	...	...	...	...	...	...	27 000	19 500	14 000
253X	...	...	...	...	...	...	...	20 000	(14 200)
	1.0 per cent Deformation Strength, psi								
Y4474X	...	...	...	...	...	...	...	...	19 500
Y3166X	...	...	...	...	...	...	26 000	19 500	14 700
Y4602X	73 000	66 000	...	48 500	39 000	31 000	22 500	15 000	(10 300)
Y4860X	...	...	...	...	...	...	...	23 000	16 000
Y4512X	...	...	...	...	...	...	27 500	19 200	13 800
Y4511X	...	...	...	...	...	...	22 000	17 000	13 000
Y4847X	...	...	...	...	...	...	23 500	17 500	12 500
Y4984X	...	...	...	...	...	32 000	26 000	18 000	12 500
253X	...	...	...	...	...	...	...	19 000	(13 500)
	0.5 per cent Deformation Strength, psi								
Y4474X	...	...	...	...	...	...	29 500	23 500	19 000
Y3166X	...	...	...	...	...	...	25 000	19 000	14 200
Y4602X	71 000	63 000	56 000	44 000	35 000	(28 000)	19 000	13 000	...
Y4860X	...	...	...	...	...	...	29 000	21 000	15 000
Y4512X	...	...	...	...	...	...	24 500	17 000	12 500
Y4511X	...	...	...	44 500	35 000	28 500	20 000	15 500	...
Y4847X	64 000	56 000	49 000	42 500	35 000	29 000	22 000	15 500	11 000
Y4984X	...	...	...	49 000	38 000	28 500	23 500	16 000	11 000
253X	...	...	...	49 000	38 500	30 500	24 500	17 000	...
	0.2 per cent Deformation Strength, psi								
Y4474X	...	...	...	...	...	...	26 000	21 500	18 000
Y3166X	...	...	...	31 500	27 000	...	21 000	16 500	13 200
Y4602X	67 000	60 000	54 000	...	...	...	14 000	...	...
Y4860X	...	...	...	30 500	27 500	...	24 000	17 500	...
Y4512X	...	...	...	...	...	...	18 500	14 000	...
Y4511X	...	...	...	...	...	...	16 500	...	...
Y4847X	...	...	...	31 500	29 500	...	16 500	12 000	...
Y4984X	...	...	...	29 000	...	...	17 000	12 500	...
253X	...	...	...	...	...	...	18 000	(11 500)	...

Note.—Parentheses around strength values indicate extrapolated values.

TABLE IX.—RUPTURE AND TOTAL DEFORMATION STRENGTHS OF TEN HEATS OF N155 SHEET MATERIAL AT 1350, 1500, AND 1650 F.

Heat No.	Stress for Rupture or Indicated Total Deformation in the Specified Time Period											
	1350 F				1500 F				1650 F			
	5 hr	20 hr	80 hr	300 hr	5 hr	20 hr	80 hr	300 hr	1 hr	5 hr	20 hr	80 hr
	RUPTURE STRENGTH, PSI											
M624	...	35 000	28 500	23 000	...	20 500	18 500	14 000	...	16 000	13 000	10 200
M206	...	37 000	29 500	24 000	...	21 000	18 000	14 500	...	16 500	12 800	9 800
M208	...	37 500	29 500	23 500	...	22 000	17 500	14 500	...	16 500	13 000	10 300
M207	...	37 000	31 000	25 500	...	21 000	18 000	15 000	...	17 000	13 500	10 500
M733	...	36 000	29 500	24 000	...	22 000	18 000	14 500	...	17 500	13 500	10 100
M737	...	37 000	30 000	24 500	...	22 000	18 000	14 500	...	16 000	13 000	10 300
M732	...	35 000	28 000	23 000	...	21 000	17 000	13 500	...	16 000	12 500	10 000
M731	...	36 000	30 000	25 000	...	22 000	18 500	16 000	...	17 000	14 000	11 500
M726	...	36 000	29 000	24 000	...	21 500	18 000	14 800	...	16 000	13 200	11 000
M730	...	34 500	28 500	24 000	...	19 500	17 000	15 000	...	17 000	13 300	10 400
	2.0 PER CENT DEFORMATION STRENGTH, PSI											
M624	35 000	29 000	24 000	(19 500)	20 000	17 500	15 500	(13 500)	16 000	13 500	11 300	9 300
M206	36 000	29 500	24 500	(20 000)	21 500	18 500	16 000	(14 000)	17 500	14 000	11 500	9 200
M208	35 000	30 500	25 000	(21 000)	21 000	18 500	16 200	(14 000)	17 500	14 500	12 000	10 000
M207	35 500	30 500	26 500	23 000	19 500	18 000	16 500	14 500	17 000	14 000	12 000	10 000
M733	34 000	30 500	25 000	(22 000)	21 500	18 500	16 000	13 800	16 500	13 200	11 000	9 100
M737	35 500	29 500	25 000	(21 000)	22 000	18 500	15 500	13 500	16 500	14 000	11 500	9 400
M732	34 000	29 000	24 000	(20 500)	20 500	18 000	14 500	(12 000)	15 000	12 500	10 700	9 200
M731	36 500	31 000	27 000	23 000	22 000	19 500	17 200	15 000	17 000	15 000	12 500	10 300
M726	35 000	29 000	24 000	(20 000)	22 000	19 000	16 000	13 800	16 000	13 500	11 700	10 100
M730	34 000	29 000	24 500	(21 000)	21 500	18 500	16 000	(14 000)	16 300	14 000	11 800	9 800
	1.0 PER CENT DEFORMATION STRENGTH, PSI											
M624	29 500	25 000	21 500	(18 000)	18 500	16 500	14 500	(13 000)	15 000	12 500	10 500	8 800
M206	31 500	26 000	21 000	(17 500)	20 000	17 500	15 000	(13 500)	16 000	13 300	11 000	8 800
M208	32 500	27 500	23 000	(19 500)	20 000	17 500	15 000	(13 000)	16 500	13 500	11 500	9 500
M207	31 000	27 500	24 000	(21 000)	18 500	17 000	15 500	13 500	15 500	13 000	11 000	9 600
M733	31 000	27 500	23 000	(20 000)	19 500	17 000	15 000	13 000	15 500	12 500	10 000	8 400
M737	31 500	26 000	21 500	(18 500)	19 500	16 800	14 500	(12 800)	15 000	13 000	10 500	8 800
M732	30 000	25 000	21 500	(18 500)	19 000	15 000	13 000	(11 000)	13 500	12 000	10 200	8 800
M731	33 000	28 000	24 000	(21 000)	21 000	18 500	16 200	14 000	16 000	14 000	11 500	9 800
M726	32 500	27 000	22 000	(18 500)	20 000	17 500	15 000	(12 500)	15 000	12 700	11 000	9 700
M730	29 000	25 000	21 500	(18 500)	19 500	17 000	15 000	(13 000)	15 500	13 000	11 000	9 200

0.5 PER CENT DEFORMATION STRENGTH, PSI												
M624	26 500	22 000	...	...	16 500	14 500	...	...	13 500	11 500	9 800	...
M206	26 000	22 000	...	...	18 000	15 000	...	...	15 000	12 200	10 000	...
M208	28 000	24 000	...	...	18 500	16 000	...	...	15 000	12 500	10 500	...
M207	27 500	24 000	...	...	17 500	16 000	...	...	14 000	12 000	10 500	...
M733	26 500	24 000	...	...	17 500	15 500	...	...	14 000	11 000	9 100	...
M737	26 500	22 500	...	...	17 000	14 500	...	...	14 000	12 000	9 700	...
M732	26 500	22 000	...	...	17 000	14 000	...	...	12 500	11 000	9 800	...
M731	27 500	24 000	...	...	19 000	17 000	...	...	14 500	13 000	10 800	...
M726	27 000	23 500	...	...	17 500	15 000	...	...	14 000	12 000	10 300	...
M730	25 500	21 000	...	...	17 500	16 000	...	...	14 500	12 000	10 000	...
0.2 PER CENT DEFORMATION STRENGTH, PSI												
M624	22 000	...	...	...	14 000	...	...	...	10 000	9 400	...	...
M206	21 500	...	...	...	15 000	...	...	...	12 500	10 200	...	...
M208	22 500	...	...	...	14 000	...	...	...	12 500	10 500	...	...
M207	21 500	...	...	...	14 500	...	...	...	12 000	10 500	...	...
M733	22 000	...	...	...	15 000	...	...	...	12 000	9 400	...	...
M737	22 000	...	...	...	14 000	...	...	...	11 500	9 400	...	...
M732	21 500	...	...	...	14 000	...	...	...	10 500	9 400	...	...
M731	21 000	...	...	...	15 500	...	...	...	12 500	10 800	...	...
M726	23 500	...	...	...	15 000	...	...	...	12 000	10 300	...	...
M730	21 000	...	...	...	15 000	...	...	...	12 000	10 000	...	...

NOTE.—Parentheses around strength values indicate extrapolated values.

of extension rods. As the specimen deformed, the mirrors were rotated and the rotation measured by a scale reflected in the mirrors to a telescope. The readings on both sides of the specimens were taken and averaged. The sensitivity of the extensometer system was 0.000003 in. per in. in the 2-in. gage length.

Inasmuch as the extensometers were attached to the shoulders of the specimen, the observed deformations included elongation in the fillet and a portion of the shoulder, as well as in the reduced section. Consequently, it was necessary to establish factors that would correct the total deformation observed to that occurring in the reduced section. That is, the total extension measurements were translated into per cent elongation of an "effective gage length." The effective gage length is the hypothetical gage length that would deform the same amount as the total deformation measured by the extensometers.

Two effective gage lengths were determined: one for the loading portion of the creep-rupture tests, and the other for the creep data obtained after the load had been applied. This was necessary because the relations between stress and strain during loading are different from those during creep.

The effective gage length during loading was determined at room temperature by several tests run on specimens using both SR-4 strain gages applied to the reduced section and the mechanical extensometers attached to the shoulders. Several independent checks were conducted to determine the effective gage length for creep in the rupture test. Specimens were gage-marked in a number of places in both the reduced section and shoulder areas and carefully measured with a vernier microscope before and after creep testing. The specimens used covered a range of temperatures, stresses, creep rates, and materials. From these data, together with the extensometer readings obtained during the tests, an effective gage length was calculated. Furthermore, the effective gage length was independently calculated on the basis of stress distribution and the integration of creep rates in the entire section between the points of attachment for the extensometers. The values obtained for the effective gage length by these calculations agreed exceptionally well with those determined experimentally.

TEST RESULTS

Tensile Properties at Room Temperature:

The results of the tension tests are summarized in Table V. It will be noted that tensile properties were uniform. The most notable exception was Inconel X, Heat Y4474X, which had abnormally low strength. If Heat Y4474X were excluded from the values for the ranges reported in Table V, the low side of the tensile strength range would have been 170,000 psi instead of the 156,600 psi shown. The other strength values were proportionately low for this heat. The duplicate specimens all agreed well in properties in every case, indicating no large variations within individual sheets.

Stress-Rupture Properties:

The stresses for rupture in the specified times are given in Tables VI to IX for all sheets. Figures 1 to 4 show the ranges in these stresses as a function of temperature. The approximate ranges in elongations for fracture are also included in the figures. Three or four tests were run on each sheet for each temperature and a stress-rupture curve plotted. The stresses reported were obtained by interpolation on the stress-rupture time curves. In most cases, the stresses

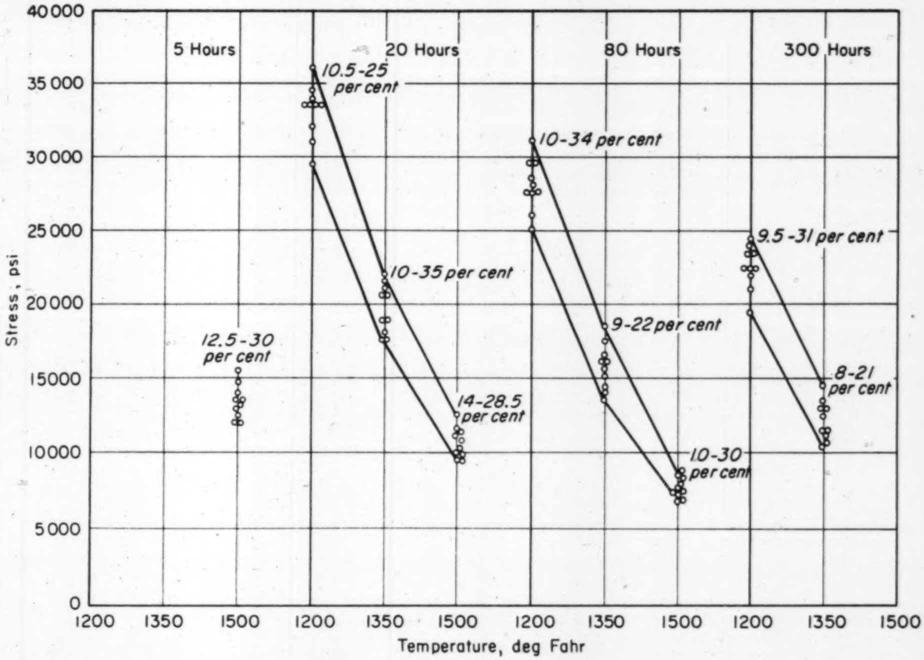

FIG. 1.—Summary of Stress-Rupture Strengths for Ten Heats of Type 321 Sheet at 1200, 1350 and 1500 F for Time Periods of 5, 20, 80, and 300 hr.

Per cent values shown on graph indicate estimated range in elongation at fracture for specified time period.

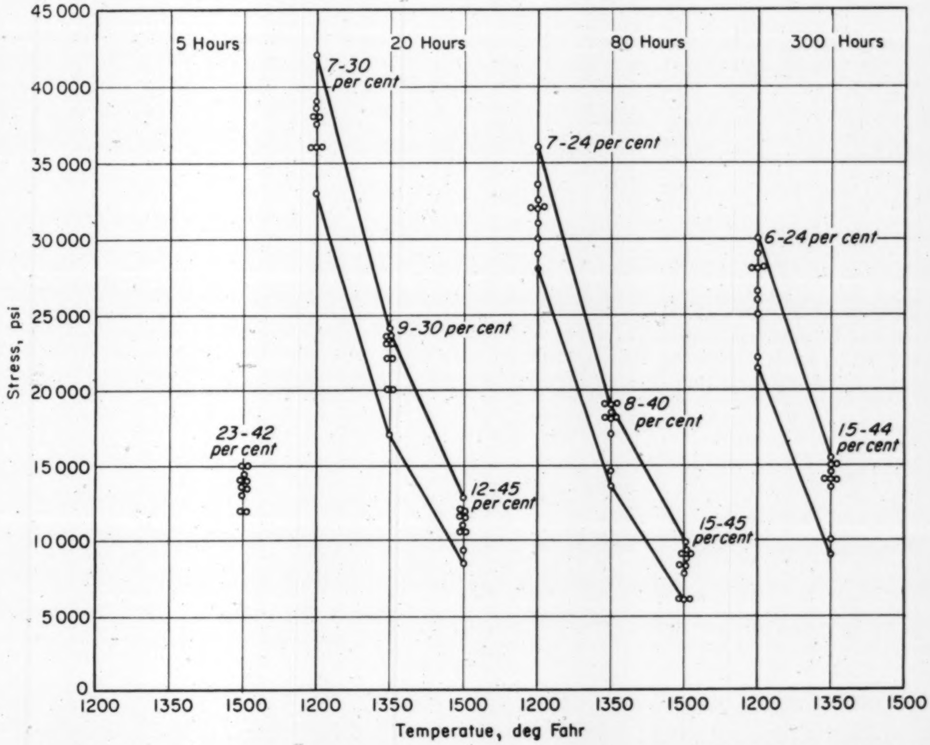

FIG. 2.—Summary of Stress-Rupture Strengths for Ten Heats of Type 347 Sheet at 1200, 1350, and 1500 F for Time Periods of 5, 20, 80, and 300 hr.

Per cent values shown on graph indicate estimated range in elongation at fracture for specified time period.

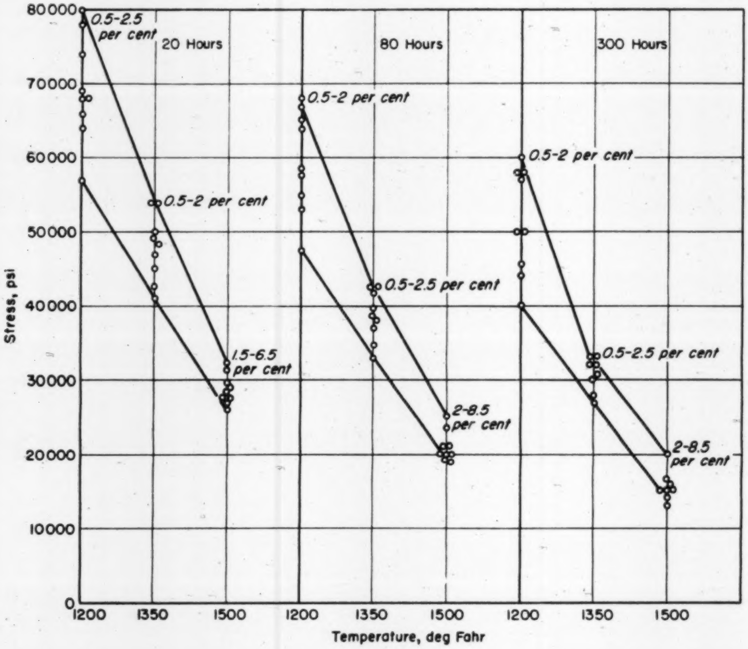

FIG. 3.—Summary of Stress-Rupture Strengths for Nine Heats of Inconel X Sheet at 1200, 1350, and 1500 F for Time Periods of 20, 80, and 300 hr.

Per cent values shown on graph indicate estimated range in elongation at fracture for specified time period.

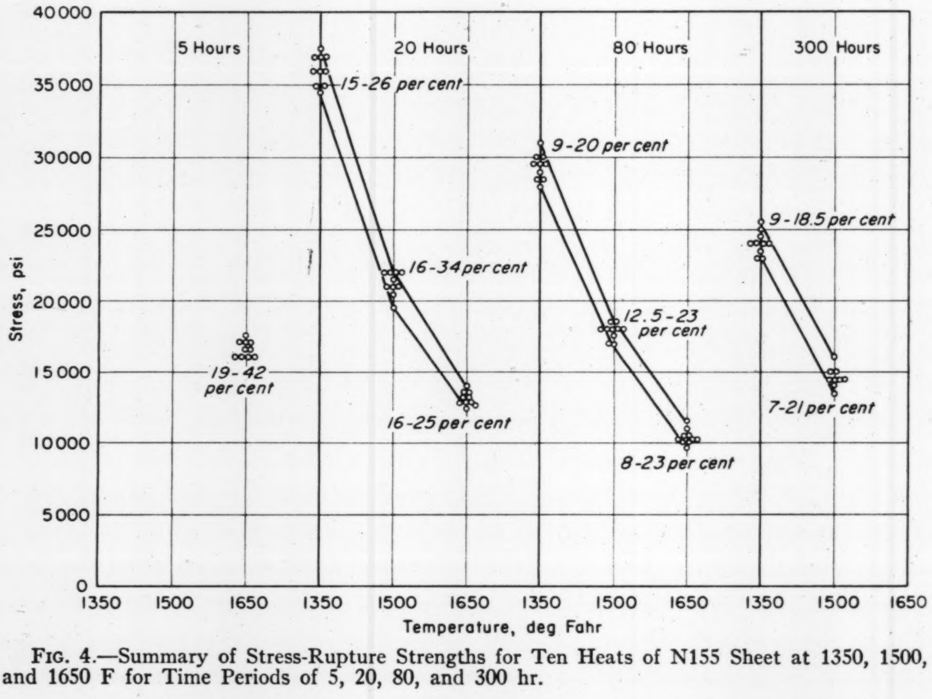

FIG. 4.—Summary of Stress-Rupture Strengths for Ten Heats of N155 Sheet at 1350, 1500, and 1650 F for Time Periods of 5, 20, 80, and 300 hr.

Per cent values shown on graph indicate estimated range in elongation at fracture for specified time period.

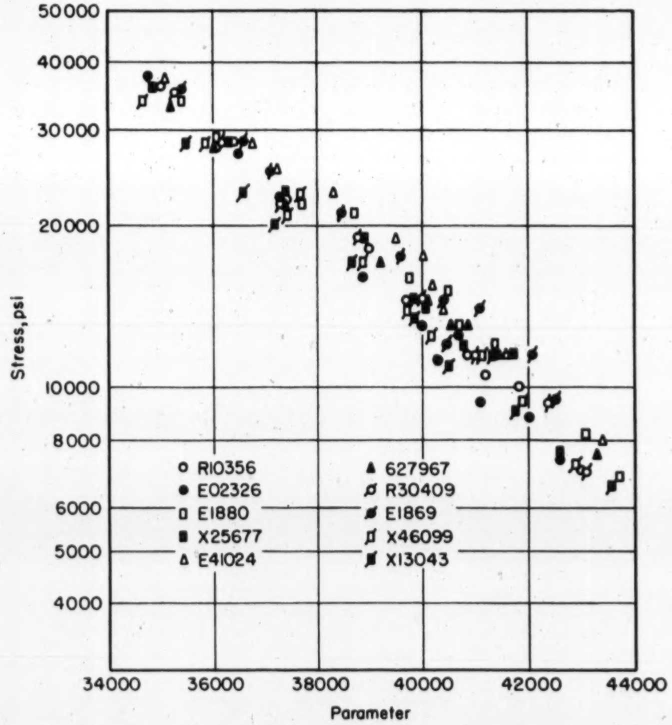

FIG. 5.—Graph of Stress *versus* Time-Temperature Parameter, $P = T\ (20 + \log t)$, for the Individual Stress Rupture Tests on Ten Heats of Type 321 Sheet Material at 1200, 1350, and 1500 F.

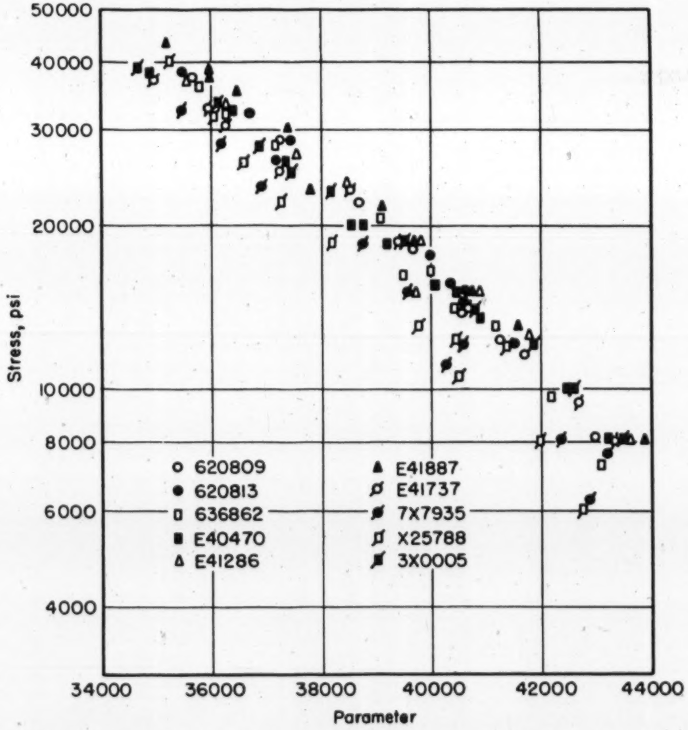

FIG. 6.—Graph of Stress *versus* Time-Temperature Parameter, $P = T\ (20 + \log t)$, for the Individual Stress Rupture Tests on Ten Heats of Type 347 Sheet Material at 1200, 1350, and 1500 F.

were adjusted so that the actual test times were not greatly different from those specified.

In conducting the tests, it was not found possible to test all heats of a given alloy at the same stresses. This was due to the spread in rupture times for a given stress being too wide to enable proper establishment of the specified rupture times. After one test point was available, the stresses were adjusted to give fracture times near those specified. For instance, for N155 the spread in rupture times for the average stress for fracture in 80 hr at 1350 F was 55 to 100 hr, a range wider than was specified for the investigation. The other materials had considerably wider variations in rupture times at a given stress. Several more tests would have been required for each rupture curve to have run tests on all heats at common stresses and also have established the specified rupture times.

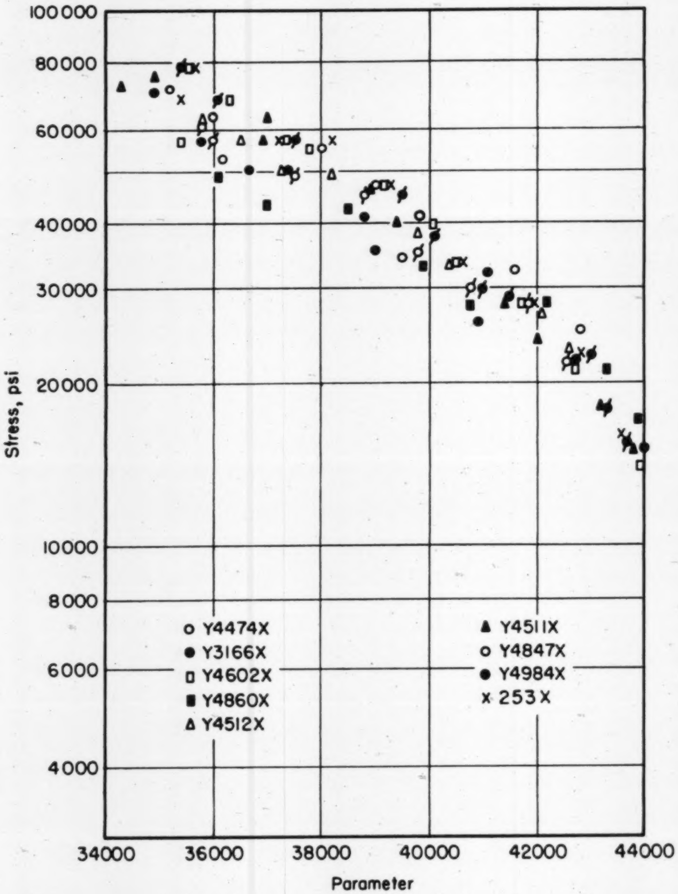

FIG. 7.—Graph of Stress *versus* Time-Temperature Parameter, $P = T\ (20 + \log t)$, for the Individual Stress Rupture Tests on Nine Heats of Inconel X Sheet Material at 1200, 1350, and 1500 F.

When the investigation was initiated, it was believed possible that the number of tests required could be reduced considerably by the use of a time-temperature parameter for correlating stress-rupture data.[3] However, as the work progressed, it became apparent that the data did not fit a single stress-parameter curve sufficiently well to predict the strength of one heat upon the curve obtained from another heat. The individual test points for each alloy are plotted on stress-parameter coordinates in Figs. 5, 6, 7, and 8. The time-temperature parameter employed was that developed by Miller and Larson where parameter = $T(C + \log t)$. Temperature, T, is expressed in degrees Rankin; the time, t, in hours; and the value for the constant, C, is usually taken as 20. It was observed that changing the value of C resulted in better agreement for the values obtained from a single heat but at the same time increased the disagreement for other heats. However, it is apparent from Figs. 5 to 8 that the agreement in rupture strengths between the various heats was not sufficient to warrant its use in the determination of the range in rupture strengths for this investigation from a master curve established from a limited number of heats. It is likewise apparent that using a limited number of tests on each heat to establish a curve would not have been reliable.

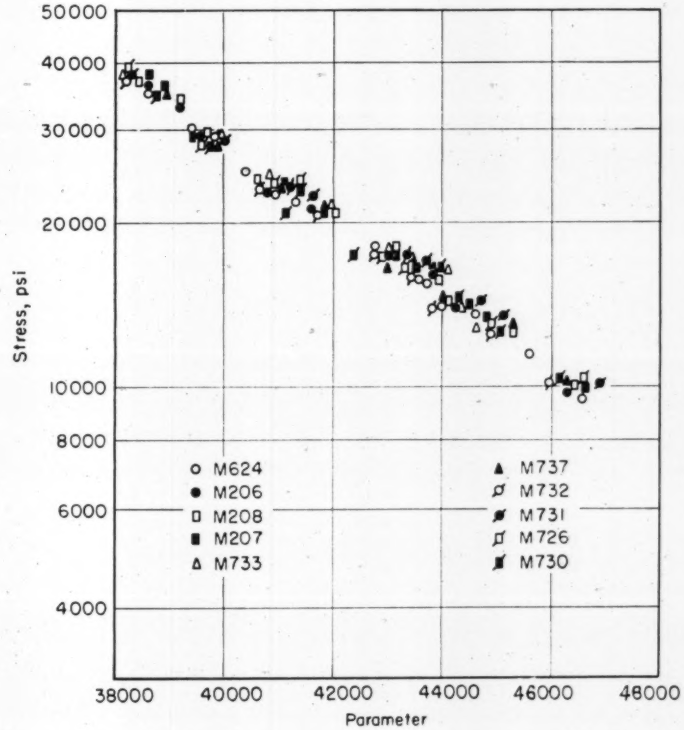

FIG. 8.—Graph of Stress *versus* Time-Temperature Parameter, $P = T\ (20 + \log t)$, for the Individual Stress Rupture Tests on Ten Heats of N155 Sheet Material at 1350, 1500, and 1650 F.

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[3] F. R. Larson and James Miller, "A Time-Temperature Relationship for Rupture and Creep Stresses," *Transactions*, Am. Soc. Mechanical Engrs., Vol. 74, No. 5, July, 1952.

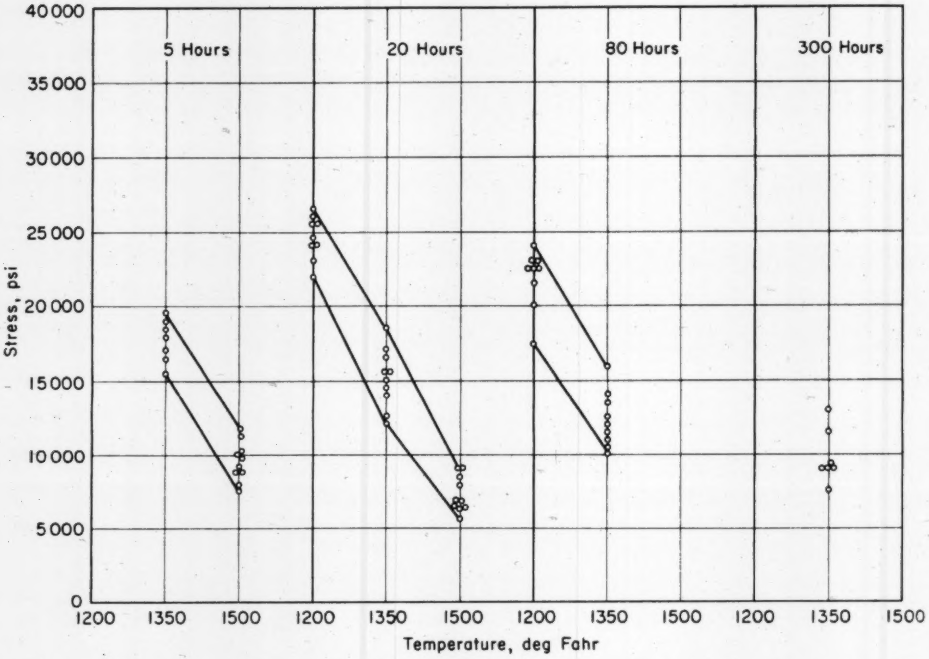

FIG. 9.—Summary of 1.0 per cent Total Deformation Strengths for Ten Heats of Type 321 Sheet at 1200, 1350, and 1500 F for Time Periods of 5, 20, 80, and 300 hr.

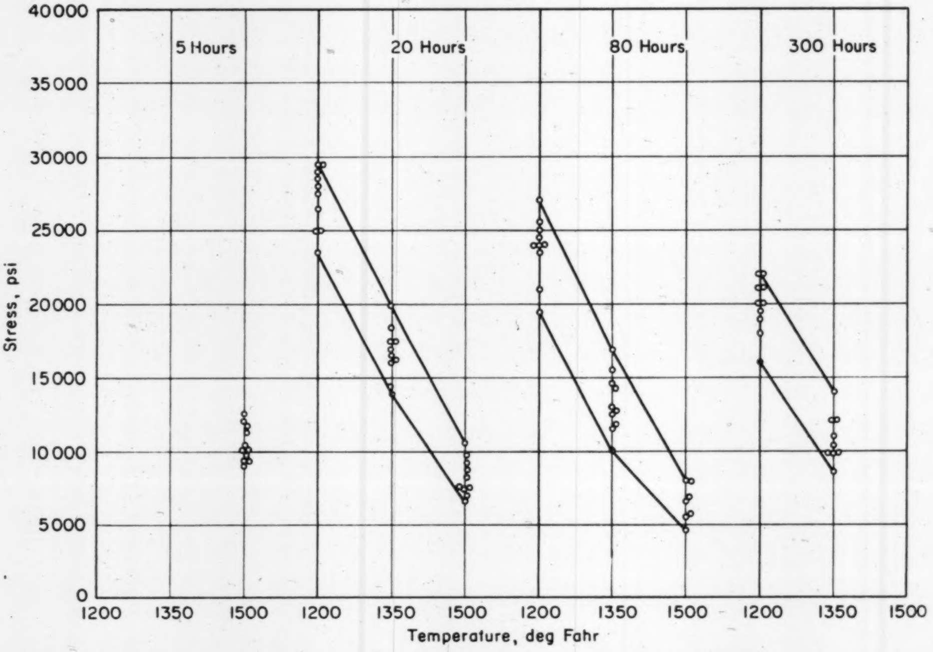

FIG. 10.—Summary of 2.0 per cent Total Deformation Strengths for Ten Heats of Type 321 Sheet at 1200, 1350, and 1500 F for Time Periods of 5, 20, 80, and 300 hr.

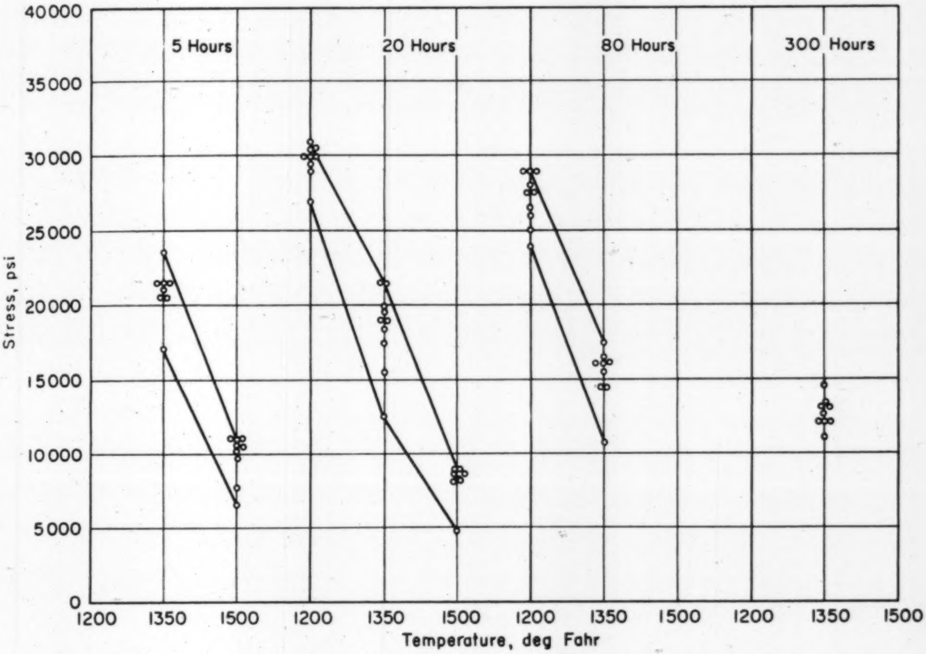

FIG. 11.—Summary of 2.0 per cent Total Deformation Strengths for Ten Heats of Type 347 Sheet at 1200, 1350, and 1500 F for Time Periods of 5, 20, 80, and 300 hr.

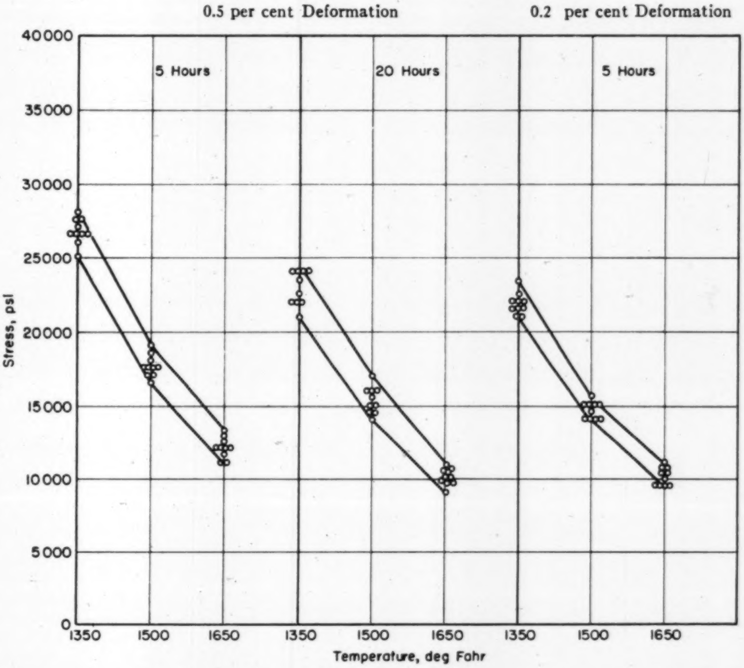

FIG. 12.—Summary of 0.5 and 0.2 per cent Total Deformation Strengths for Ten Heats of N155 Sheet at 1350, 1500, and 1650 F for Time Periods of 5 and 20 hr.

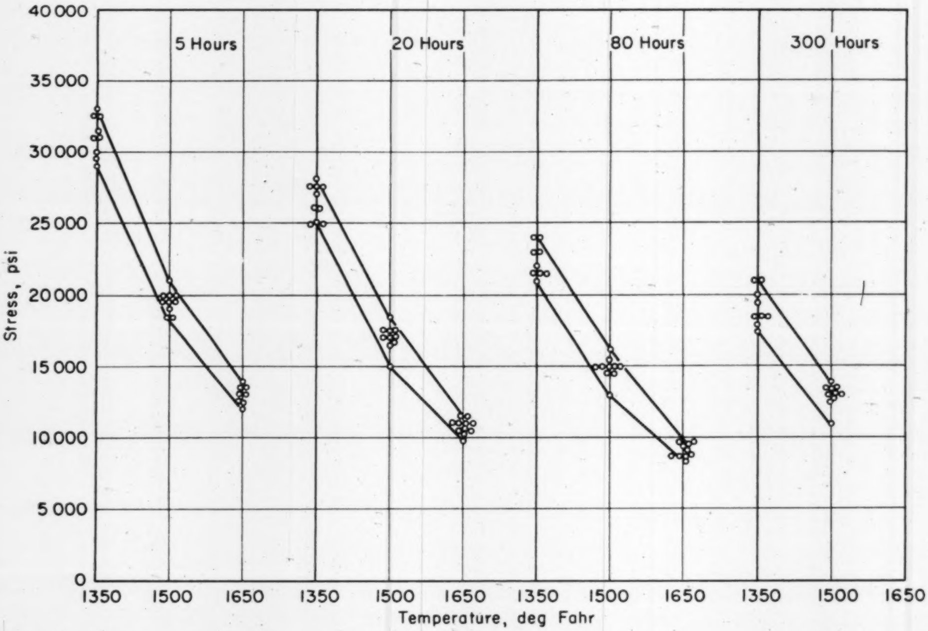

FIG. 13.—Summary of 1.0 per cent Total Deformation Strengths for Ten Heats of N155 Sheet at 1350, 1500, and 1650 F for Time Periods of 5, 20, 80, and 300 hr.

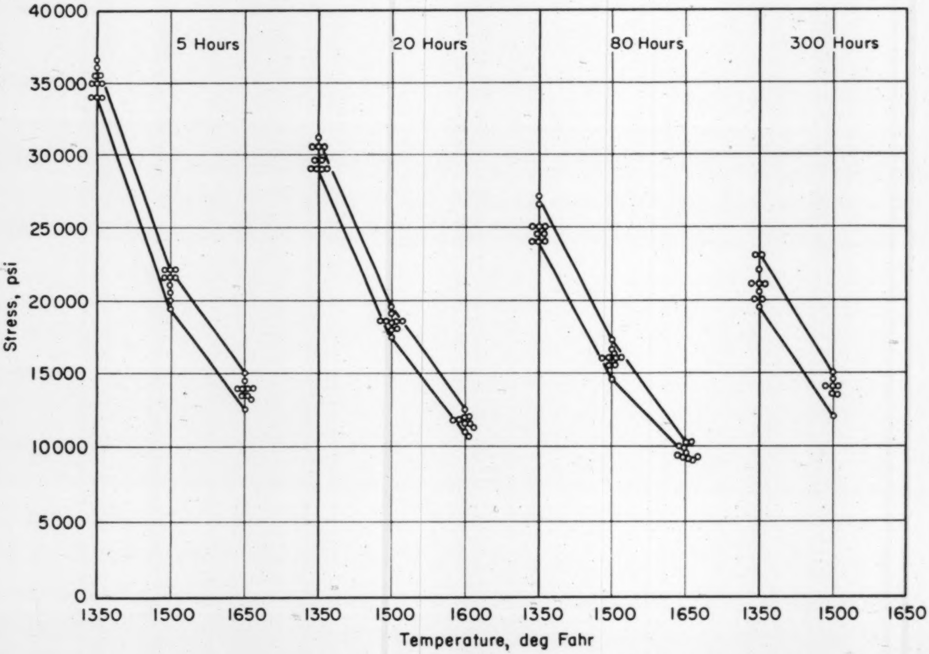

FIG. 14.—Summary of 2.0 per cent Total Deformation Strengths for Ten Heats of N155 Sheet at 1350, 1500, and 1650 F for Time Periods of 5, 20, 80, and 300 hr.

TABLE X.—STATISTICAL EVALUATION OF STRESS RUPTURE AND TOTAL DEFORMATION STRENGTHS OF TEN HEATS OF TYPE 321 SHEET AT 1200, 1350, AND 1500 F.

Rupture or Total Deformation Time, hr	Temperature, deg Fahr	Number of Heats[a]	Range in Rupture or Deformation Strength, psi	Average Strength, psi	Standard Deviation, psi	Average ± 3 Times Standard Deviation, psi
RUPTURE STRENGTHS						
20...........	1200	10	29 500-36 000	33 100	1740	27 900-38 300
80...........		10	25 000-31 000	28 000	1660	23 000-33 000
300...........		10	19 500-24 500	22 550	1405	18 300-26 800
20...........	1350	10	17 500-22 000	19 650	1580	14 900-24 400
80...........		10	13 500-18 500	15 700	1490	11 200-20 200
300...........		10	10 500-14 600	12 200	1250	8 400-15 900
5...........	1500	10	12 000-15 500	13 400	1080	10 200-16 600
20...........		10	9 500-12 500	10 650	900	7 900-13 300
80...........		10	6 600- 8 800	7 550	710	5 400- 9 700
2.0 PER CENT TOTAL DEFORMATION STRENGTHS						
20...........	1200	10	23 500-29 500	27 200	1930	21 400-33 000
80...........		10	19 500-27 000	23 800	2010	17 800-29 800
300...........		10	16 000-22 000	19 850	1750	14 600-25 100
20...........	1350	10	14 000-20 000	16 800	1680	11 800-21 800
80...........		10	10 000-17 000	13 250	2020	7 200-19 300
300...........		9	8 600-14 000	10 750	1580	6 000-15 500
1...........	1500	8	11 500-15 200	13 150	1260	9 400-16 900
5...........		10	9 000-12 500	10 550	1160	7 100-14 000
20...........		10	6 800-10 500	8 300	1080	5 100-11 500
80...........		7	4 600- 7 900	6 400	1140	3 000- 9 800
1.0 PER CENT TOTAL DEFORMATION STRENGTHS						
20...........	1200	9	22 000-26 500	24 550	1380	20 400-28 700
80...........		9	17 500-24 000	21 850	1915	16 100-27 600
5...........	1350	7	15 500-19 500	17 700	1330	13 700-21 700
20...........		10	12 000-18 500	15 100	1880	9 500-20 740
80...........		9	10 000-16 000	12 350	1790	7 000-17 700
300...........		7	7 600-13 000	9 750	1670	4 700-14 800
1...........	1500	10	10 400-14 200	12 100	1180	8 600-15 600
5...........		10	7 600-11 700	9 550	1260	5 800-13 300
20...........		10	5 600- 9 000	7 250	1160	3 800-10 800
0.5 PER CENT TOTAL DEFORMATION STRENGTHS						
20...........	1200	7	19 000-25 000	22 350	1680	17 300-27 400
5...........	1350	9	13 500-19 500	16 400	1590	11 600-21 200
20...........		10	9 200-17 000	13 500	2130	7 100-19 900
80...........		8	8 700-14 000	10 750	1800	5 300-16 100
1...........	1500	10	8 700-12 800	10 850	1310	6 900-14 800
5...........		10	6 300-10 500	8 400	1400	4 200-12 600
20...........		8	5 300- 8 100	6 450	950	3 600- 9 300
0.2 PER CENT TOTAL DEFORMATION STRENGTHS						
5...........	1350	10	9 600-17 000	13 700	2180	7 200-20 200
20...........		8	10 000-16 000	11 900	1910	6 200-17 600
1...........	1500	10	7 200-11 000	9 050	1255	5 300-12 800
5...........		9	5 500- 8 600	6 750	1000	3 700- 9 700

[a] Number of heats for which data were available for indicated strength value.

TABLE XI.—STATISTICAL EVALUATION OF STRESS RUPTURE AND TOTAL DEFORMATION STRENGTHS FOR TEN HEATS OF TYPE 347 SHEET AT 1200, 1350, AND 1500 F.

Rupture or Total Deformation Time, hr	Temperature, deg Fahr	Number of Heats[a]	Range in Rupture or Deformation Strength, psi	Average Strength, psi	Standard Deviation, psi	Average ± 3 Times Standard Deviation, psi
RUPTURE STRENGTHS						
20	1200	10	33 000–42 000	37 400	2250	30 600–44 100
80		10	28 000–36 000	31 600	2160	25 100–38 100
300		10	21 500–30 000	26 400	2700	18 300–34 500
20	1350	10	17 000–24 000	21 800	2080	15 600–28 000
80		10	13 500–19 000	17 350	1770	12 000–22 700
300		10	9 000–15 500	13 450	2070	7 200–19 700
5	1500	10	12 000–15 000	13 620	1005	10 600–16 600
20		10	8 400–12 800	10 920	1250	7 200–14 700
80		10	6 000– 9 800	8 210	1230	4 500–11 900
2.0 PER CENT TOTAL DEFORMATION STRENGTHS						
20	1200	9	27 000–31 000	29 700	1110	26 400–33 000
80		10	24 000–29 000	27 150	1660	22 200–32 100
5	1350	8	17 000–23 500	20 900	1710	15 800–26 000
20		10	12 500–21 500	18 450	2620	10 600–26 300
80		9	10 600–17 500	15 250	1850	9 700–20 800
300		8	11 000–14 500	12 700	980	9 800–15 600
1	1500	9	10 000–15 000	12 900	1265	9 100–16 700
5		10	6 600–11 000	9 950	1420	5 700–14 200
20		9	4 800– 9 000	8 150	1185	4 600–11 700
1.0 PER CENT TOTAL DEFORMATION STRENGTHS						
5	1350	9	14 000–21 500	19 200	2030	13 100–25 300
20		10	10 500–19 500	16 650	2650	8 700–24 600
80		9	9 000–16 800	14 100	1880	8 500–19 700
1	1500	9	7 800–12 800	11 300	1350	7 200–15 300
5		10	5 300–10 200	8 680	1720	3 500–13 800
20		7	7 100– 8 400	7 800	437	6 500– 9 100
0.5 PER CENT TOTAL DEFORMATION STRENGTHS						
5	1350	10	12 000–19 000	17 200	1990	11 200–23 200
20		10	9 000–18 000	14 950	2540	7 300–22 600
1	1500	9	6 200–11 500	9 800	1635	4 900–14 700
5		8	4 100– 9 400	8 220	1590	3 400–13 000
0.2 PER CENT TOTAL DEFORMATION STRENGTHS						
5	1350	10	9 400–17 500	14 590	2365	7 500–21 700
1	1500	7	4 600– 9 800	8 470	1625	3 600–13 300
5		7	7 200– 8 000	7 450	154	7 000– 7 900

[a] Number of heats for which data were available for indicated strength value.

Total Deformation Strengths:

The creep curve for each rupture test was plotted. The available times for total deformations of 0.2, 0.5, 1.0, and 2.0 per cent were taken from these curves, and curves were then plotted for stress *versus* the time for these total elongations for each test temperature on each heat. Values were then interpolated for the stresses for the deformations in 1, 5, 20, 80, and 300 hr, depending on what data were available. These latter values are given in Tables VI to IX. Where the data are sufficiently complete, the ranges are shown as a function of temperatures in Figs. 9 to 14.

TABLE XII.—STATISTICAL EVALUATION OF STRESS RUPTURE AND TOTAL DEFORMATION STRENGTHS FOR NINE HEATS OF INCONEL X SHEET AT 1200, 1350, AND 1500 F.

Rupture or Total Deformation Time, hr	Temperature, deg Fahr	Number of Heats[a]	Range in Rupture or Deformation Strength, psi	Average Strength, psi	Standard Deviation, psi	Average ± 3 Times Standard Deviation, psi
RUPTURE STRENGTHS						
20...........	1200	9	57 100–80 000	69 300	6700	49 200–89 400
80...........		9	47 500–68 000	59 500	6580	39 800–79 200
300...........		9	40 000–60 000	51 400	6800	31 000–71 800
20...........	1350	9	41 000–54 000	47 900	4250	35 200–60 600
80...........		9	33 000–42 500	38 600	3230	28 900–48 300
300...........		9	27 000–33 000	30 900	2060	24 700–34 100
20...........	1500	9	26 000–32 000	28 700	1900	23 000–34 400
80...........		9	19 000–25 000	21 000	1890	15 300–26 700
300...........		9	13 000–20 000	15 400	1870	9 800–21 000
2.0 PER CENT TOTAL DEFORMATION STRENGTHS						
80...........	1500	6	17 500–20 500	19 100	1060	15 900–22 300
300...........		5	11 500–14 800	13 600	1030	10 500–16 700
1.0 PER CENT TOTAL DEFORMATION STRENGTHS						
20...........	1500	6	22 000–27 500	24 600	1950	18 800–30 400
80...........		8	15 000–23 000	18 500	2180	12 000–25 000
300...........		9	10 300–19 500	14 000	2450	6 700–21 300
0.5 PER CENT TOTAL DEFORMATION STRENGTHS						
20...........	1500	9	19 000–29 500	24 100	3470	13 700–34 500
80...........		9	15 000–23 500	17 700	2730	9 500–25 900
300...........		6	11 000–19 000	13 800	2770	5 500–22 100
0.2 PER CENT TOTAL DEFORMATION STRENGTHS						
20...........	1500	9	14 000–26 000	19 100	3660	8 100–30 100
80...........		7	11 500–21 500	15 100	3370	5 000–25 200

[a] Number of heats for which data were available for indicated strength value.

The deformations reported are the total deformations from loading and creep. Some values were not obtained for the following reasons: (1) deformation during loading exceeded the desired values; (2) the total deformation exceeded those of interest in much less

TABLE XIII.—STATISTICAL EVALUATION OF STRESS RUPTURE AND TOTAL DEFORMATION STRENGTHS FOR TEN HEATS OF N155 SHEET AT 1350, 1500, AND 1650 F.

Rupture or Total Deformation Time, hr	Temperature, deg Fahr	Number of Heats[a]	Range in Rupture or Deformation Strength, psi	Average Strength, psi	Standard Deviation, psi	Average ± 3 Times Standard Deviation, psi
RUPTURE STRENGTH						
20	1350	10	34 500–37 500	36 100	970	33 200–39 000
80		10	28 000–31 000	29 350	840	26 800–31 900
300		10	23 000–25 500	24 050	757	21 800–26 300
20	1500	10	19 500–22 000	21 250	783	18 900–23 600
80		10	17 000–18 500	17 850	503	16 300–19 400
300		10	13 500–16 000	14 630	627	12 700–16 500
5	1650	10	16 000–17 500	16 550	522	15 000–18 100
20		10	12 500–14 000	13 180	399	12 000–14 400
80		10	9 800–11 500	10 410	476	9 000–11 800
2.0 PER CENT TOTAL DEFORMATION STRENGTHS						
5	1350	10	34 000–36 500	35 050	819	32 600–37 500
20		10	29 000–31 000	29 750	750	27 500–32 000
80		10	24 000–27 000	24 950	986	22 000–27 900
300		10	19 500–23 000	21 100	1156	17 600–24 600
5	1500	10	19 500–22 000	21 150	840	18 600–23 700
20		10	17 500–19 500	18 450	522	16 900–20 000
80		10	14 500–17 200	15 940	664	13 900–17 900
300		10	12 000–15 000	13 810	739	11 600–16 000
1	1650	10	15 000–17 500	16 530	727	14 300–18 700
5		10	12 500–15 000	13 820	657	11 800–15 800
20		10	10 700–12 500	11 600	496	10 100–13 100
80		10	9 100–10 300	9 640	420	8 400–10 900
1.0 PER CENT TOTAL DEFORMATION STRENGTHS						
5	1350	10	29 000–33 000	31 150	1266	27 400–35 000
20		10	25 000–28 000	26 450	1127	23 100–29 800
80		10	21 000–24 000	22 300	1052	19 100–25 500
300		10	17 500–21 000	19 100	1158	15 600–22 600
5	1500	10	18 500–21 000	19 550	723	17 400–21 700
20		10	15 000–18 500	17 030	853	14 500–19 600
80		10	13 000–16 200	14 870	782	12 500–17 200
300		10	11 000–14 000	12 930	758	10 700–15 200
1	1650	10	13 500–16 500	15 350	777	13 000–17 700
5		10	12 000–14 000	12 950	538	11 300–14 600
20		10	10 200–11 500	10 820	482	9 400–12 300
80		10	8 400– 9 800	9 140	458	7 800–10 500
0.5 PER CENT TOTAL DEFORMATION STRENGTHS						
5	1350	10	25 500–28 000	26 700	813	24 300–29 100
20		10	21 000–24 000	22 900	1068	19 700–26 100
5	1500	10	16 500–19 000	17 600	700	15 500–19 700
20		10	14 000–17 000	15 350	839	12 000–18 000
1	1650	10	12 500–15 000	14 100	700	12 000–16 200
5		10	11 000–13 000	11 920	589	10 200–13 700
20		10	9 100–10 800	10 050	467	8 600–11 500

TABLE XIII.—*Concluded.*

Rupture or Total Deformation Time, hr	Temperature, deg Fahr	Number of Heats[a]	Range in Rupture or Deformation Strength, psi	Average Strength, psi	Standard Deviation, psi	Average ± 3 Times Standard Deviation, psi
0.2 PER CENT TOTAL DEFORMATION STRENGTHS						
5...........	1350	10	21 000–23 500	21 850	709	19 700–24 000
5...........	1500	10	14 000–15 500	14 600	538	13 000–16 200
1...........	1650	10	10 000–12 500	11 750	813	9 300–14 200
5...........		10	9 400–10 800	9 900	521	8 400–11 600

[a] Number of heats for which data were available for indicated strength value.

time than 300 hr; (3) in many cases creep rates were so high that deformations of interest were exceeded in less than 1 hr; (4) the total extension to fracture was less than 2 per cent.

Statistical Evaluation:

The tensile and stress-rupture data were analyzed statistically insofar as it was considered legitimate from the data available.

The range, average, and standard deviation were determined for each alloy for the tensile strength, yield strength, proportional limit, and elongation values obtained from the tension tests. These values are shown in Table V, together with the maximum difference in properties observed for one heat of the alloy.

Similar values—range, average, and standard deviation—were obtained for all the stress-rupture strength data and for total deformation data where it was believed that sufficient data were available to warrant statistical treatment. These values are given in Tables X to XIII, together with the number of heats used in the calculation and the spread in values obtained by using the average plus or minus three times the standard deviation ($\pm 3\sigma$).

In general, the data appeared to follow a rather normal frequency distribution, and the agreement between the actual range in values determined and the probable range estimated by the average $\pm 3\sigma$ was fairly good. Thus it might be expected that the sample was representative of the universe, although a much larger sample would be necessary to substantiate this statement.

For the tensile data, the major exception to this statement was the properties of the Inconel X sheet. The estimated range indicated that considerably higher strengths might be expected than were actually obtained.

The agreement between the actual and estimated ranges in rupture strengths was quite good, although the estimated range for Inconel X indicated that heats with considerably higher and lower strengths than actually were obtained might be expected, especially at 1200 and 1350 F.

The statistical analysis of the total deformation strengths showed good agreement between actual and estimated ranges when sufficient data were available. However, it should be recognized that the heats for which no values were reported fall outside of the reported ranges and that the actual range in strength would be greater if sufficient data were available to establish these points.

It should be emphasized that the statistical evaluation is based on rupture and total deformation strengths obtained from a plot of stress against time for rupture or given total deformation, and that the values obtained from such plots are subject to statistical variation in themselves. That is, three to five tests run at a given temperature under different stresses were used to establish the stress-rupture or total deformation strengths, and since some scatter was observed for these points, the individual strengths for a single heat are subject to a plus or minus variation. However, since only three to five tests were run at each temperature and since these tests were obtained from somewhat widely spread locations within a single sheet, it was not thought feasible to attempt a statistical analysis of each heat. Furthermore, the range in stress-rupture strengths obtained from the stress-parameter curves of Figs. 5 through 8 where all the individual points are plotted is only slightly greater than that obtained using the values taken from the individual rupture strengths.

DISCUSSION

Data are presented on the ranges in rupture and total deformation strengths of commercially produced sheet of 18 Cr-8 Ni (Ti) (Type 321), 18 Cr-8 Ni (Cb-Ta) (Type 347), N155, and Inconel X alloys for three time periods at three temperatures. Sample sheets from ten separate heats of each alloy were used. In general, these data represent a more complete survey of the high-temperature properties of a given product than is usually available. The additional statistical analysis shows designers rather completely what to expect from the products.

The reasons for the range in properties are not well established. The high-temperature properties of the alloys are known to be influenced by heat-treating temperatures, cold work, and variations in composition. Most studies of variability also indicate that differences arise from working conditions prior to final heat treatment and from unidentified heat-to-heat variations. In general, the interrelations of these variables make it very difficult to establish specific causes. For these reasons, correlations between properties and compositions or tensile properties were not carried out. Any trends that might be indicated would have to be verified under more closely controlled conditions than were used for this study.

In general, where test material was obtained from more than one source, the sheets from one source tended to show properties that grouped more closely than the total spread. This would be expected for an established practice in one plant. All of the sheets coming from one producer quite certainly explains the small spread in properties for N155 alloy. On the other hand, all Inconel X sheets were also made by one producer. Inconel X, however, is dependent on precipitation of compounds of nickel with aluminum + titanium for its high strength. Alloys exhibiting such precipitation reactions might be expected to be considerably more sensitive to prior history than the other alloys. Heat treatments of the other alloys mainly dissolve precipitated carbides and remove cold work. It will be noted that Inconel X, Heat Y4474X, which had the low tensile strength at room temperature, had about average properties at 1200 F and was on the high side of the range at 1500 F.

Due to space limitations, the actual test data are not included. In general, quite good stress-rupture time curves were obtained. There was, however, some scatter that appeared to be related to slight variations in specimens taken from the different locations in the sheets.

The stress-rupture time curves were not parallel to one another but were at varying angles. This would be expected for the several possible metallurgical variations affecting the properties. The distinct nature of the individual stress-rupture time curves indicated metallurgical variation as the responsible cause of the spread in data and not sampling or testing variables.

The properties at high temperatures are expressed in every case as the variation in stress for rupture in a given time. It should be recognized, however, that the variation in time for rupture at a fixed stress was considerable. As mentioned previously in the case of least scatter, N155, rupture times at 1350 F would have varied from 55 to 100 hr under the average stress for rupture in 80 hr. In a more extreme case, that of Inconel X tested at 1200 F, the average stress for rupture in 80 hr gave times from 24 to 350 hr. This condition arises from the rather flat slope of the usual log-log stress-rupture time curves. Furthermore, the variation between specimens from an individual sheet run at a constant stress would have been considerable, even though the average stress-rupture time curves were quite good.

Acknowledgment:

The Aviation Panel of the ASME-ASTM Joint Committee on the Effect of Temperature on the Properties of Metals acknowledges with thanks the cooperation of the following companies who provided test stock for the investigation: Crucible Steel Co., Eastern Stainless Steel Corp., Haynes Stellite Co., The International Nickel Co., Republic Steel Corp., and United States Steel Corp.

DISCUSSION

MESSRS. C. W. PHILLIPS[1] AND M. J. SINNOTT[1] (*presented in written form*).—It appears that this report has been misnamed. It is purported to be a "statistical evaluation" when actually it should perhaps be termed a "survey." While we appreciate what the Aviation Panel of the ASTM-ASME Joint Committee on the Effect of Temperature on the Properties of Metals and the authors were attempting to accomplish and are in sympathy with their aims, it is apparent that the treatment of the work reported falls far short of being statistical and does violence to what is known as statistical analysis.

A statistical evaluation, if valid, will be reflected in the planning of the experimental program, in the appreciation of the significance of statistical methods, and in the treatment of the data obtained. The present work appears to be deficient in all three of these respects.

The authors treat the data from the ten heats of a given alloy as though they originated from the same statistical universe. This is something which cannot be assumed but must be proven mathematically from the results of properly planned tests. No knowledge of the relation of variances obtained at particular temperatures and times for all heats of an alloy to the variance of the stress-time regression is derivable from the experimental procedure. The authors are aware that within-heat variance exists but do not associate this with the observed between-heat variance. The former may be of the same magnitude as the latter. Some information exists on the extent of the variance in commercial aluminum.[2] If some estimate of the standard deviation in the rupture time at various stresses and temperatures had been obtained within heats, then a comparison with the between-heat results by an analysis of variance would have made possible some concrete statements on the homogeneity of the alloys tested. It would appear that in the present case the decision to attempt a statistical analysis was not made until the work was completed. This is always a serious error since a properly planned program, carried out with the assistance of a statistician, will in the long run save much time, money, and effort, and yield much more useful information.

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[1] Assistant Professor and Associate Professor, respectively, Metallurgical Engineering, University of Michigan, Ann Arbor, Mich.

The significance of statistical methods of analysis appears to have been lost to the authors in some instances. For example, their statement that the universe is normal is a subjective conclusion based on samples of 10, a wholly inadequate quantity to determine the form of any naturally occurring universe—in fact, as already mentioned, they have not ascertained the existence of a universe. The agreement between the actual range of the experimental data and the 3σ limits is certainly to be expected, almost regardless of the nature of the universe. Tchebycheff's inequality reveals that all of a sample of 9, as in the case of Inconel X, will fall within the 3σ limits and that 9 out of a sample of 10 will do the same no matter what the nature of the parent distribution.[3] The somewhat more stringent Camp-Meidell requirements of a unimodal distribution having the same mode and arithmetic mean show that all of a sample of 10 will fall within 3σ limits. The projection of the observation that the experimental range falls within the 3σ limits to the conclusion that the sampling technique is good is completely unwarranted. Similarly, the expectation that the Larson-Miller plots would reduce the number of tests necessary is without foundation. It is a basic fact in statistics that only by increasing the number of observations can the reliability of the measured property be increased, and this only when the measurements are obtainable from a single universe. Recasting the data using an empirical relation involving known variables (time and temperature) must inevitably increase the variance obtained, as was found by the authors.

The omission of the original test data is most unfortunate, at least from the statistician's point of view. Its presentation would have made possible whatever statistical treatment the reader might desire. For example, the tension data, while scanty, could have been treated to reveal within-heat and between-heat variance and from this the homogeneity of variances. A complication which might arise is that if the room-temperature tensile strength does show that control exists, this does not necessarily indicate that control would exist in the creep-rupture properties at elevated temperatures. The authors' observation that sheets from one source tended to show properties that grouped more closely than the total spread could have been checked quantitatively from an analysis of variance. The fact that all of the N-155 alloy came from one producer in no way explains its small variance; the authors appear to reject the probability that it has a low intrinsic variance, while in the next sentence they accept the probability that the Inconel X has a high intrinsic variance. The authors' reference to stress-rupture time curves as being "quite good" and as having a "distinct nature" are of course not based on statistical calculations. As a matter of fact, the true function of statistics is to remove bias resulting from just such personal conclusions drawn from the observations.

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[2] C. W. Phillips and M. J. Sinnott, "A Statistical Study of the Stress-Rupture Test," *Transactions*, Am. Soc. Metals, Vol. 46, p. 63 (1953).

[3] Manual on Quality Control of Materials, Am. Soc. Testing Mats., p. 23 (1951). (Issued as separate publication *ASTM STP No. 15-C*.)

Finally, it would appear that the reasons for the range in properties, mentioned in Discussion, are completely established. In all systems which are investigated with respect to a particular property, many chance sources of variation are operating simultaneously to affect the property. The number and magnitude of such chance causes combine to yield the range. Undoubtedly the factors mentioned are some of the unassignable causes. Apparently the authors intended to say that those causes which probably contribute most to the variance are as yet unknown, and in this we certainly concur. The discovery of such variables is in effect one of the principal functions of the statistical method. The statement to the effect that the scatter in results is not due to sampling or testing variables is not true. The summation of chance variables to produce a property variation is the reason for the sampling—to reveal in as unbiased a way as possible such variations. The metallurgical variables and testing variables are *per se* the components of the sampling variations.

Mr. A. B. Wilder[4] (*by letter*).—The creep-rupture data presented by Messrs. A. I. Rush and J. W. Freeman are very interesting. Although a limited amount of data are available for statistical analysis, it is seldom possible in the field of creep to make a comparison of a number of different heats of steel melted under similar conditions to a definite chemical range. The authors have made this comparison under the limitations outlined and therefore the results should be interpreted accordingly. On the basis of the standard deviation obtained for rupture strength, it may be of interest to compare material used for seamless pipe with material in sheet form.

The results in the accompanying Table XIV have been obtained for AISI 321 and 347 steel before and after 10,000 hr exposure without stress at 1200 F. The material was in the annealed condition.

The rupture strength before exposure is within the range of $\pm 3\sigma$. After exposure there was a decrease in the rupture strength of the type 347 steel, but for all practical purposes it remained within 3σ range. The type 321 steel behaved in a similar manner with the exception that two of the rupture strength values slightly increased after exposure.

TABLE XIV.—STRESS RUPTURE PROPERTIES.

Rupture or Total Deformation Time, hr	Rupture or Deformation Strength, psi			
	Type 321		Type 347	
	Before Exposure	10 000 hr Exposure	Before Exposure	10 000 hr Exposure
20.....	29 000	29 800	32 000	29 900
80.....	24 000	25 000	28 000	25 000
300.....	20 500	20 100	26 000	21 800

Messrs. A. I. Rush and J. W. Freeman (*authors' closure*).—Mr. Wilder's data are a welcome addition to the data in the paper and indicate that the range in strength for type 347 reported covers the possible range for this alloy extremely well, as the authors were well aware.

The discussion by Phillips and Sinnott of the statistical aspects of the paper raised no points which had not been fully recognized. In order to develop a practical program certain short cuts from the ideal statistical approach had to be used. The time and cost of the idealized program would have been astronomical.

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[4] Chief Metallurgist, National Tube Division U. S. Steel Corp., Pittsburgh, Pa.

Contrary to the discussers' opinion, and for this very reason, extensive recourse to advice from statisticians was used by the Aviation Panel in planning the program. The statistical groups consulted, however, had extensive experience in the application of statistical methods to creep-rupture data and were, therefore, aware of certain features of such tests that could be accepted without the prohibitive extensive testing programs deemed necessary by the discussers.

Single sheets from individual heats were accepted as the best possible compromise in obtaining typical samples of the alloys. Experience had established that variations in properties would be magnified to the greatest extent by this procedure. Any evaluation of within-heat variance would require that a number of sheets be tested for at least one heat from each producer. Most metallurgists, however, would be unwilling to accept such evaluation from only one heat from each producer inasmuch as the factors involved in within-heat variance could not be expected to be the same for all heats.

The decision to use three to five tests at each temperature for evaluation of individual sheets was based on the experience of statisticians working in the field. The derived stress-rupture time curve provides values for rupture in definite time periods which were as reliable as those based on a number of tests at a single stress. The reliability of such values is further increased by similar curves at neighboring temperatures. The requirement that the family of curves should be consistent prevents abnormal results from unusual variations in properties or testing techniques for individual specimens.

The discussers do not accept the validity of this approach, probably due to inexperience with creep-rupture testing. Their cited variations for repeated testing of commercial aluminum is so extreme that those experienced with the creep-rupture test cannot understand their data. Reproducibility of creep-rupture data is merely a function of the uniformity of test material and reproducibility of testing technique. The data cited must represent an extreme case of variability in either or both factors. If such variation had been present in the sheet materials studied for the paper, it would not have been possible to establish consistent stress-rupture time curves. No difficulty was encountered in selecting stresses to give desired rupture time periods once two tests were available to establish the slopes of the stress-rupture time curves. The main variation between sheets of each alloy was in the slopes of the stress-rupture time curves, as would be expected from metallurgical considerations. Scatter of data from tests within each sheet was a minor factor. It turned out to be much less than the authors had anticipated at the time the investigation was undertaken. The fact that the stresses for rupture at specific time periods derived from the spread in test points at those times was the same as those derived from individual stress-rupture time curves further substantiates the validity of the stresses reported. No undue averaging by the stress-rupture-time curves was necessary.

It should be pointed out in view of the discussion that the failure of the Miller-Larson parameter method to reduce testing was not due to the reason cited by the discussers. As was pointed out in the paper, each sheet had a characteristic stress-parameter curve at each temperature which could not be predicted from one test at a given temperature or from several tests at one temperature. This curve is a function of the properties of each sheet and not of statistical variation within a given sheet. Or more properly, it is due to a limitation of the correlation method between temperatures, rather than to any statistical feature.

The criticism of the universe to which statistical treatments were applied is admittedly valid. The authors were fully aware of this and had carefully reviewed the treatment of the data with statisticians at the University. It is presumed that the discussers did not carefully read the interpretations of this feature of the paper. The degree to which the possible ranges in properties were covered by the samples of each alloy (the validity of the assumption that the universe was properly represented) depends on the restrictions of metallurgical variables imposed by the applicable specifications. This is a very difficult matter to establish with the information at hand.

From a purely metallurgical viewpoint the authors know the variables responsible for the ranges in properties. The unknown factor is in the degree to which prior history, final treatments, and chemical composition are restricted by the specifications. The authors know that the ranges in properties for types 321 and 347 were nearly the same as is usual for the alloys in any form. The authors, however, felt that it is possible under the specification to obtain both higher and, what is more important, lower values with certain production practices. For this reason, even though the samples appeared to follow a normal frequency distribution indicating possible 3σ limits of considerably greater confidence than the minimum of 88.9 per cent based on small sample statistics, the statement was made that a much larger sample would be required to verify this feature.

In the case of Inconel X, the probability of the sample being representative of a universe composed of material from all sources is much less. The strength values obtained were, in general, so far below the usual range for the alloy in other forms that it appears quite certain that the manufacturing practice of the single source represents certain features that could easily be altered by other sources or even, for that matter, by the producer represented. Thus, while a normal distribution of properties was obtained for Inconel X, it probably is mostly representative of a single established practice unless the restrictions of the specification are unusually effective. Certainly great care should be exercised in applying even the 3σ limits of strength reported for Inconel X from other sources or after any subsequent treatments of sheet.

In the case of the N-155 alloy, the values were on the high side of the range possible for the alloy. Again there is a serious question as to how well the samples represent those which might be obtained from all sources. The authors recognize that duplication of the practice of the producer represented would give strengths well within the limits cited. The question remains as to whether this would be attained in other sources.

The statement that the low variance observed for N-155 alloy was due to all of the sheets being obtained from one supplier was not intended to reject the possibility of low intrinsic variance contributing to the narrow range in properties observed. On the contrary, it was pointed out that the Inconel-X material, also received from a single supplier, exhibited a wide range in properties because it has high intrinsic variance as a result of the sensitivity of the Al + Ti precipitation hardening of the alloy to prior history and treatment conditions. On the other hand, the authors know from considerable research experience on the variables affecting the properties of N-155 that a wider range in properties is to be expected if the alloy were obtained from several sources, although produced to the same specification.

As previously mentioned considerable work was carried out with statisticians in preparation of the data. The authors, perhaps, were unduly conscious of the importance of the reliability of the lowest values reported. The engineer, particularly in using the data for critical applications such as aircraft, is concerned with the possibility of obtaining unduly low-strength material. It is agreed that more precise treatment of the data by small sample methods would have permitted the calculation of more exact confidence limits. For example, the limits for 99 per cent confidence that the lowest expected value would not be below a minimum value could have been calculated. However, in view of the scanty data and the authors' knowledge of the materials, there was reluctance to imply more confidence in such limits than was perhaps warranted. Consequently, the admittedly rough but commonly reported 3σ limits were used. Additional possible treatment of the data from the viewpoint of reliability of the average values, such as was done by Harold F. Dodge in the Marburg lecture[5] was omitted because the authors felt that attention should be placed on the lower values rather than on the average.

Those familiar with the practical problems of obtaining extensive creep-rupture data will recognize that the paper presents data which statistically defines the ranges in properties for four commercial alloys in sheet form far more completely than has ever been done previously. From a purely statistical viewpoint, there are a number of shortcomings. However, these represent the best possible compromises based on statistical considerations for a practical testing program. Insofar as creep-rupture properties are concerned the paper certainly warrants the term "Statistical Evaluation" in the title.

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[5] See p. 603 this publication.

INVESTIGATIONS RELATING TO THE USE OF FLY ASH AS A POZZOLANIC MATERIAL AND AS AN ADMIXTURE IN PORTLAND-CEMENT CONCRETE*

BY L. JOHN MINNICK[1]

This report summarizes the results of a number of investigations on the use of fly ash as a pozzolanic material and as an admixture in portland cement concrete. The studies were also designed to develop information on numerous technical questions that had been raised by ASTM members.

The report includes round-robin tests which were set up to assist in the evaluation of specifications and methods of tests being considered by ASTM committees, particularly the Sponsoring Committee for Blended Cements, a subcommittee of C-1, and Subcommittee III-h on Methods of Testing and Specifications for Admixtures of Committee C-9. In addition, various independent studies are reported which were carried out by ASTM members and other test engineers.

The Corps of Engineers, U. S. Army, has carried out an extensive program which has a direct bearing on the round-robin tests mentioned above, since several of the same sources of fly ash were used in both programs. The Corps of Engineers has kindly provided some of its data for inclusion in this report. The Bureau of Reclamation also carried out a group of tests on a large number of fly ash samples and submitted the results to ASTM committees; some of its data are also reproduced in this report.

The present report also includes information taken from a comprehensive compilation of data that was submitted by the author in June, 1948, to ASTM Committees C-1 on Cement, C-9 on Concrete and Concrete Aggregates, C-12 on Mortars for Unit Masonry, C-13 on Concrete Pipe, and C-15 on Manufactured Masonry Units. That compilation contained a considerable amount of available technical information that had been accumulated over a period of some 20 to 30 years pertaining to the use of fly ash in portland cement compositions for structural concrete, concrete pipe, and masonry units. Some data were also included showing the effect of intergrinding fly ash with portland cement clinker, but most of the information referred to the use of fly ash as an admixture to or merely blended with the cement and other constituents of the compositions. Results of freezing-and-thawing tests that were run on specimens of concrete containing fly ash, both with and without additions of air-entraining agents, were reported.

The results are presented in condensed form. The numerical data given in the tables have been reduced to a minimum, and only the average values are indicated. Where possible the use of graphical methods has been employed. No attempt has been made to make the identification of the sources of information complete, although in most cases the references are listed.

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13–18, 1954.

[1] G. & W. H. Corson, Inc., Plymouth Meeting, Pa.

OUTLINE OF INVESTIGATIONS AND RESULTS

In order to simplify the presentation, the results have been arranged into four sections. The methods of test are basically those described in ASTM Method C 311 - 53 T[2] except where otherwise noted. There are certain observations which may be made in connection with the data as follows:

1. The results when plotted show, in a number of cases, poor correlation between the variables being considered. Nevertheless, these particular graphs are included since they answer questions that have been raised.

2. The differences obtained in the results are primarily one of degree, there being no sharp demarcation between so-called unsatisfactory and satisfactory materials.

3. No single property of fly ash can be used as a basis of evaluation. It is necessary to consider each individual property in the light of all other properties.

4. It is evident from the results that some of the tests are not essential to the evaluation of fly ash as an admixture in concrete or as a pozzolanic material. It is expected that ultimately the specifications will be simplified and will include only those items that relate directly to the effect of fly ash in portland cement or in lime compositions. These may include such items as the water requirement, compressive strength, reduction in mortar bar expansion, and perhaps loss on ignition.

TABLE I.—RESULTS OF CHEMICAL ANALYSES IN ROUND-ROBIN TESTS EVALUATING THE PROPOSED SPECIFICATION FOR FLY ASH AS AN ADMIXTURE IN CONCRETE.

Sample	Chemical Analysis, per cent						Loss on Ignition, per cent	Moisture, per cent	Fixed Carbon, per cent	Exchangeable Alkali, per cent
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3				
No. 1	44.17	28.65	17.28	2.79	0.89	0.39	4.97	0.21	4.63	1.02
No. 2	39.74	27.17	12.29	1.89	0.55	0.57	17.94	0.38	16.93	0.82
No. 3	36.46	25.34	19.01	4.97	0.84	0.54	14.48	0.28	12.12	...
No. 4	47.44	30.39	13.89	1.82	0.79	0.23	4.74	0.23	3.98	1.21
No 5	41.75	25.09	6.62	0.99	0.86	0.54	19.51	0.36	18.18	1.79
No 6	49.53	26.92	10.75	1.28	1.05	0.28	4.36	0.14	3.89	1.40
No. 7	38.98	26.24	15.46	5.99	0.99	1.18	8.46	0.33	6.84	2.22
No. 8	34.01	20.15	26.43	7.66	1.63	1.34	4.72	0.41	3.91	1.39
No. 9	36.31	27.05	18.08	3.93	1.31	0.49	14.49	0.24	13.73	...
No. 10	36.70	23.13	22.67	7.06	1.01	1.24	6.15	0.28	5.41	1.18
No. 11	43.22	27.92	15.89	2.22	1.06	0.38	7.78	0.20	7.12	...
No. 12	47.32	27.61	9.64	1.42	0.68	0.43	10.03	0.32	8.70	1.54
No. 13	46.54	19.67	18.20	5.28	1.19	2.81	2.58	0.41	0.89	2.98
No. 14	41.76	17.50	18.49	9.68	1.06	3.59	2.34	0.47	1.42	...
No. 15	45.45	17.60	20.03	7.52	1.16	2.73	1.77	0.27	0.82	3.98
No. 16	47.54	20.81	19.22	4.86	1.20	2.26	1.49	0.44	0.56	3.04
No. 17	43.94	22.58	19.62	1.58	0.71	0.46	9.37	0.25	8.83	1.95
No 18	47.71	28.73	10.63	1.43	0.66	0.60	8.51	0.35	5.89	1.66
No 19	43.72	22.22	22.87	2.89	1.14	0.76	4.34	0.30	3.36	1.19
No. 20	45.73	25.22	18.35	3.00	0.96	0.55	3.75	0.47	3.43	...

NOTE.—Samples tested in accordance with ASTM Method C 311, 1953 Supplement to Book of ASTM Standards, Part 3. Results are averages of values obtained by cooperating laboratories. For complete results, see reports to Subcommittee III-h of Committee C-9, Feb. 29, 1952, and Subcommittee of C-1, Sponsoring Committee on Blended Cements, June 17, 1952.

Cooperative Tests:

The cooperative tests that were run on fly ash were carried out chiefly by five cooperating laboratories with supporting tests from several other individuals and organizations.[3] The samples of fly ash that were used in the study were supplied

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[2] Tentative Methods of Test for Fly Ash as an Admixture for Portland Cement Concrete (C 311 - 53 T), 1953 Supplement to Book of ASTM Standards, Part 3.

[3] A complete list of laboratories and individuals is found at the end of this report.

TABLE II.—RESULTS OF PHYSICAL TESTS OF ROUND-ROBIN TESTS EVALUATING THE PROPOSED SPECIFICATION FOR FLY ASH AS AN ADMIXTURE IN CONCRETE.

Sample	Sieve Sizes, Per Cent Retained						Fineness Specific Surface Blaine, sq cm per g	Specific Gravity	Water Requirement[a]	Reduction Mortar Expansion
	8	16	30	50	100	325				
No. 1	0.01	0.07	0.43	2.23	8.33	31.64	3155	2.31	103.1	59.5
No. 2	0.01	0.07	0.20	0.42	3.23	22.30	5394	2.28	107.7	55.4
No. 3	0	0.04	0.10	0.61	5.12	33.02	3780	2.26	104.6	59.6
No. 4	0	0	0.03	0.21	3.21	23.04	3566	2.24	101.0	47.5
No. 5	0.01	0.02	0.13	0.38	3.21	25.90	5379	2.14	112.3	65.5
No. 6	0	0	0.01	0.15	4.36	37.59	3218	2.18	103.0	50.8
No. 7	0	0.01	0.19	0.84	2.79	20.70	3848	2.48	98.3	46.3
No. 8	0	0.01	0.05	0.36	1.14	10.84	3372	2.63	96.4	65.0
No. 9	0	0.01	0.08	0.32	1.73	20.49	3200	2.34	106.0	38.0
No. 10	0	0.01	0.03	0.75	4.60	29.10	2913	2.46	102.2	62.3
No. 11	0.01	0.02	0.10	0.58	4.44	24.00	4040	2.35	99.3	57.0
No. 12	0.01	0.04	0.10	1.17	4.11	29.05	4545	2.20	105.4	65.8
No. 13	0.50	0.55	1.32	2.32	3.83	12.33	4405	2.53	91.6	73.7
No. 14	0.05	0.55	0.96	1.73	3.73	11.54	3955	2.50	91.0	...
No. 15	0.05	0.05	0.20	0.60	1.35	8.10	3543	2.52	90.3	60.0
No. 16	0	0.23	0.48	0.92	2.74	11.14	3545	2.49	90.1	67.7
No. 17	0	0.04	0.09	0.75	3.29	16.36	3214	2.40	101.4	66.2
No. 18	0.01	0.01	0.02	0.12	6.60	26.41	3619	2.18	103.1	64.5
No. 19	0	0	0.01	0.03	0.82	19.25	3233	2.51	101.0	65.9
No. 20	0	0.01	0.04	0.18	1.73	20.13	3165	2.40	99.5	...

NOTE.—See Note on Table I.

[a] 35 per cent replacement of portland cement.

Sample	Per Cent of Strength of Non-Fly Ash Mix Used in Compressive Strength Tests							
	35 Per Cent Replacement							25 Per Cent Replacement
	Cured 72 F		Cured 100 F				Cured 28 Days, 100F; 2 Months, 72 F	28 Days, 100 F
	28 Days	3 Months	7 Days	14 Days	28 Days[b]	90 Days		
No. 1	70.2	82.2	57.4	77.5	80.1	81.3	91.7	94.4
No. 2	...	...	...	...	74.6	...	91.6	86.0
No. 3	66.1	78.0	59.0	63.0	74.2	72.1	79.7	85.3
No. 4	...	...	...	...	85.6	...	96.6	90.7
No. 5	58.5	...	39.4	63.5	58.6	...	67.4	91.3
No. 6	57.0	71.0	50.9	64.1	80.8	80.5	78.5	78.6
No. 7	110.0	...	102.0	77.2	101.2	...	108.0	108.2
No. 8	71.4	102.8	63.5	82.4	101.8	102.4	99.8	101.1
No. 9	54.8	77.6	45.5	62.8	82.3	84.6	86.2	91.8
No. 10	92.0	...	46.5	...	85.3	...	84.2	93.9
No. 11	75.0	84.7	53.1	74.1	80.7	90.6	95.4	105.7
No. 12	...	...	...	...	91.1	...	92.6	100.4
No. 13	...	...	90.3	103.4	106.9	...	116.0	121.5
No. 14	88.5	102.8	75.7	94.9	102.0	111.7	93.6	114.0
No. 15	...	...	...	...	98.1	...	113.9	120.4
No. 16	85.1	109.8	77.9	101.1	115.4	116.3	119.7	119.3
No. 17	70.8	99.2	61.0	85.4	88.3	110.0	95.2	99.6
No. 18	72.8	80.9	55.7	79.8	82.4	96.8	86.5	90.1
No. 19	94.0	...	...	...	93.6	...	76.5	95.1
No. 20	64.9	90.4	69.9	85.8	93.0	96.5	97.1	89.8

[b] **These values are the pozzolanic strength index values used in the graphs.**

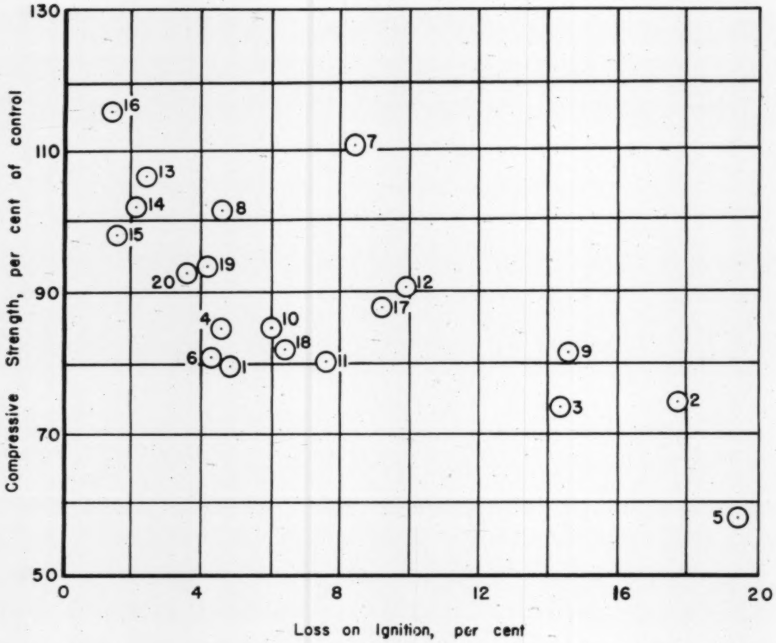

FIG. 1.—Effect of Loss on Ignition of Fly Ash on the Compressive Strength (Pozzolanic Strength Index) of Fly Ash Portland-Cement Mortar Cubes.

Age—28 days, cured at 100 F.

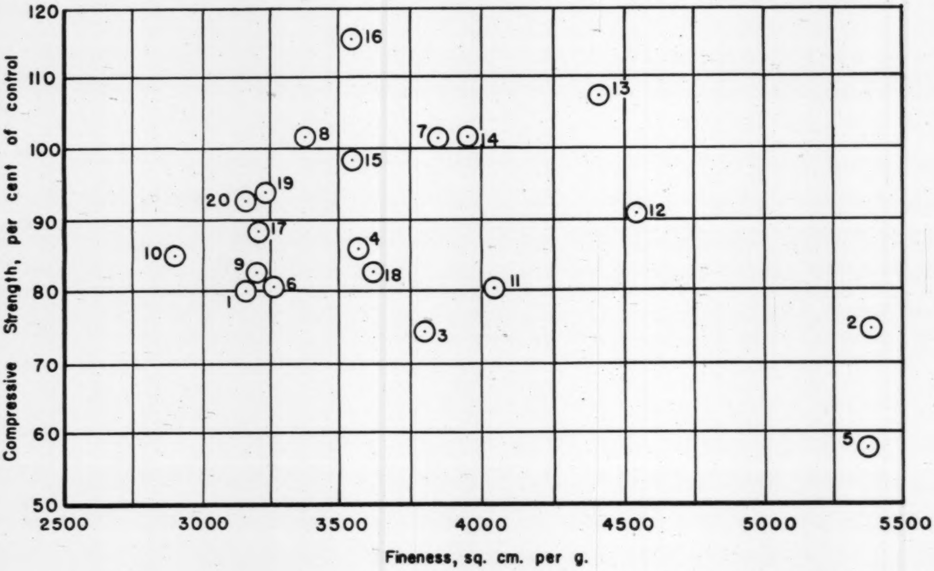

FIG. 2.—Effect of Fineness of Fly Ash on the Compressive Strength (Pozzolanic Strength Index) of Fly Ash Portland-Cement Mortar Cubes.

Age—28 days, cured at 100 F.

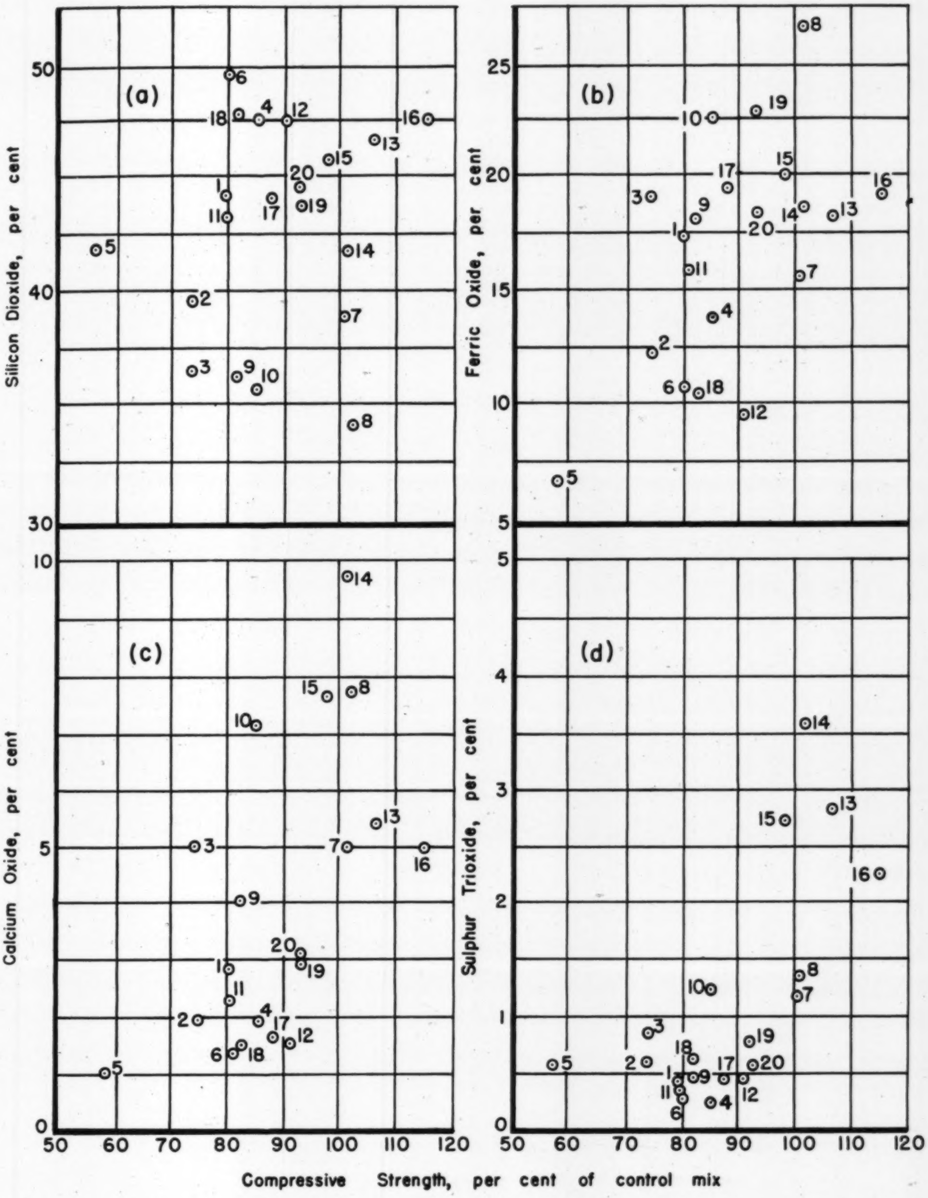

FIG. 3.—Relationship of Various Chemical Constituents of Fly Ash to the Compressive Strength (Pozzolanic Strength Index) of Fly Ash Portland Cement Mortar Cubes.

Age—28 days, cured at 100 F.

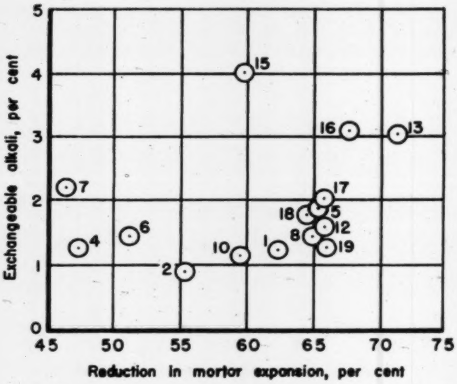

FIG. 4.—Relationship between Alkali and Mortar Expansion.

by a number of public utilities.[4] This program ultimately divided itself into four main parts:

(*a*) Physical and chemical tests made in accordance with the Tentative Methods C 311.

(*b*) Physical tests evaluating proposed specifications for blended portland-fly ash cement.

(*c*) Supplementary tests on concrete using fly ash primarily as an admixture

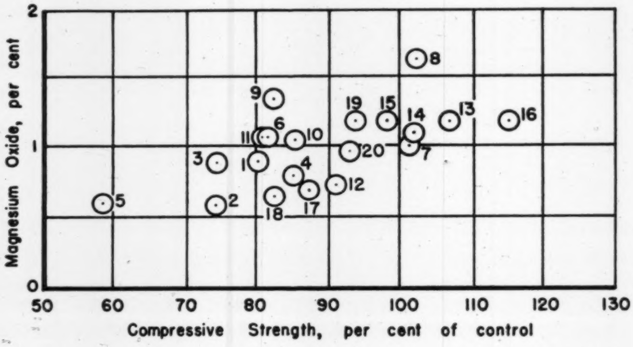

FIG. 5.—Relationship Between MgO and Compressive Strength (Pozzolanic Strength Index). Age—28 days, cured at 100 F.

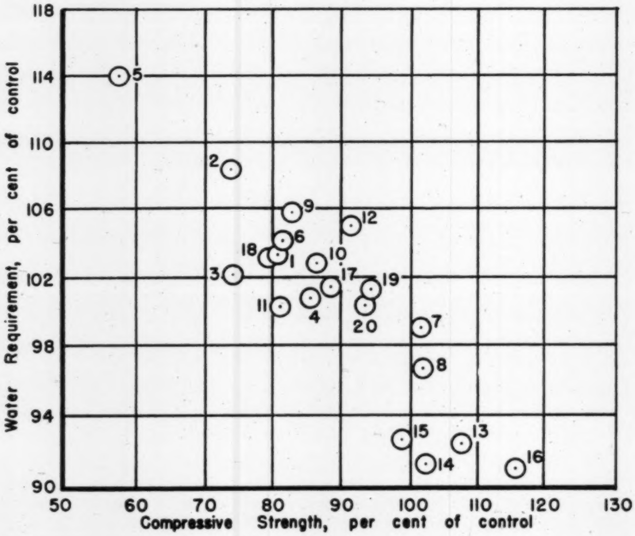

FIG. 6.—Relationship Between H_2O Requirement and Compressive Strength (Pozzolanic Strength Index).
Age—28 days, cured at 100 F

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[4] The companies supplying fly ash are listed at the end of this report.

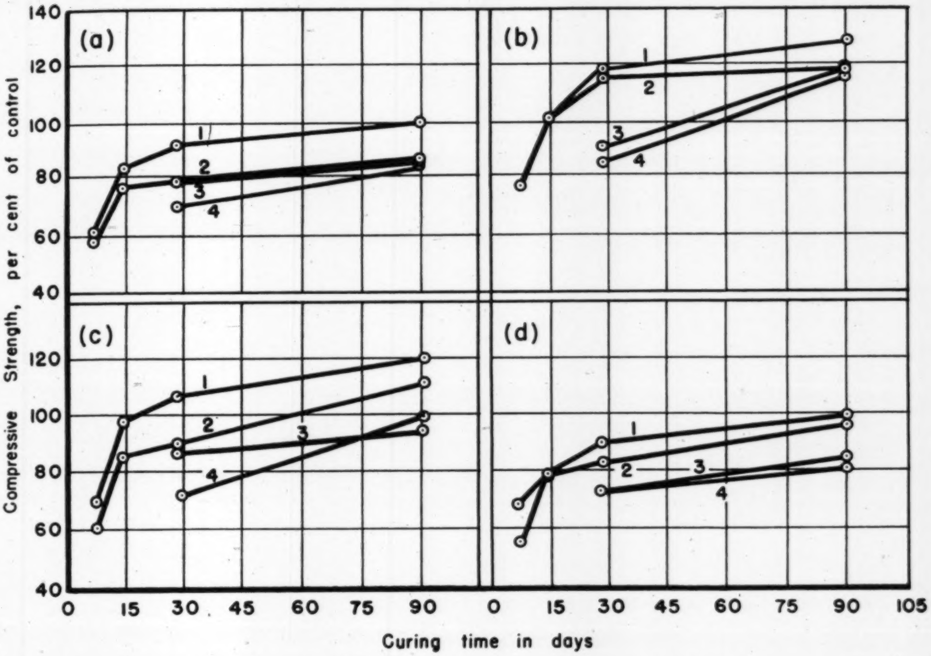

FIG. 7.—Effect of Curing Conditions on the Compressive Strength of Mortar Cubes.

Portland cement replaced with equal absolute volume of fly ash.

1—25 per cent replacement cured at 100 F.	(*a*) Fly Ash Sample No. 1.
2—35 per cent replacement cured at 100 F.	(*b*) Fly Ash Sample No. 16.
3—25 per cent replacement cured at 73 F.	(*c*) Fly Ash Sample No. 17.
4—35 per cent replacement cured at 73 F.	(*d*) Fly Ash Sample No. 18

(tested in accordance with ASTM Specification C 226 - 52 T).[5]

(*d*) Supplementary chemical and physical tests that were carried out in order to answer questions raised by committee members. These questions related to such matters as the effect of fineness, ignition loss, SO_3 content, alkali content, MgO content, water requirement, silica, and alumina of the fly ash on the performance of both portland cement mortar and concrete. Questions concerned with the effect of fly ash on air content, durability, shrinkage, strength, and pozzolanic activity were also considered. In addition, the variations in test procedures were studied—for example, determination of proper method of storage for the cubes

TABLE III.—ANALYSIS OF PORTLAND CEMENT USED BY COOPERATING LABORATORIES FOR PORTLAND-FLY ASH CEMENT TESTS.

	Type I	Type II
CHEMICAL CONSTITUENTS, PER CENT		
SiO_2	19.78	21.46
Fe_2O_3	2.50	4.08
Al_2O_3	6.10	4.92
CaO	63.70	62.25
MgO	3.53	3.66
SO_3	2.17	1.94
Loss on Ignition	1.04	0.57
Total	98.82	98.88
C_4AF	7.6	12.4
C_3A	12.0	6.2
C_3S	13.0	27.2
C_2S	58.0	45.7
$CaSO_4$	3.7	3.3
PHYSICAL PROPERTIES		
Water, per cent	73	71
Flow, in	2.5	2.8
Air, per cent	7.9	9.6

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[5] Tentative Specifications for Air-Entraining Additions for Use in the Manufacture of Air-Entraining Portland Cement (C 226 - 52 T), 1952 Book of ASTM Standards, Part 3, p. 26.

TABLE IV.—RESULTS OF ROUND-ROBIN TESTS EVALUATING THE PROPOSED SPECIFICATION FOR PORTLAND-FLY ASH CEMENT.

Fly Ash	Fineness			Time of Set		$CaSO_4$ (SO_3, g per liter)	Mortar Cubes Compressive Strength (73 F), 1 day Moist, psi		
	325 Sieve, Per Cent Retained	Specific Surface Air Permeability		Initial	Final		2 days H_2O	6 days H_2O	27 days H_2O
		sq cm per g	Porosity						
				TYPE IF[a]					
Control	...	3535	0.50	1:15	3:50	...	2273	2721	3970
No. 1	17.25	3430	0.50	4:43	8:70	0.00	1275	1960	2957
No. 1—10%	11.64	...	0.50	1:40	4:40	0.03	1500	2326	3584
No. 1—40%	19.6	...	0.52	2:45	5:45	0.03	764	1165	2044
No. 2	13.6	3690	0.50	...	...	0.00	1452	2077	2735
No. 3	17.25	3730	0.51	2:40	6:15	0.06	935	1676	2914
No. 4	18.20	...	...	4:15	8:00	0.00	1008	1900	3275
No. 5	13.19	3970	0.53	1:05	4:15	0.00	1077	1735	2660
No. 6	14.4	3490	0.50	6:30	11:00	0.00	1407	2139	2775
No. 7	17.70	...		3:30	7:30	0.00	1367	2383	3708
No. 8	11.95	3645	0.50	3:35	7:43	0.17	1691	2481	3627
No. 9	14.15	3585	0.51	2:54	6:19	0.02	816	1754	2959
No. 10	11.80	3860	0.51	3:20	5:35	0.01	1666	1510	2862
No. 11	15.25	3660	0.50	4:73	8:30	0.00	1340	2069	3525
No. 12	15.84	3700	0.48	1:38	4:03	0.02	1621	1721	2990
No. 13	...	...	...	...	...	...	...	...	2438
No. 14	13.20	3670	0.48	4:15	6:95	0.53	1596	2366	3612
No. 15	19.7	...	...	3:15	7:00	0.37	1592	2567	3775
No. 16—25%	11.95	3905	0.48	3:33	6:65	0.06	1410	2091	3131
No. 17	14.00	3320	0.5	4:13	8:07	0.00	1350	2055	2904
No. 17—10%	4.96	...	...	1:45	4:45	0.05	1520	1770	3875
No. 17—40%	12.40	...	...	3:50	5:05	0.07	697	1008	1984
No. 18	15.0	4100	0.51	2:23	5:45	0.05	1329	1754	3019
No. 19	12.4	3350	0.5	6:25	9:40	0.00	1523	2363	3433
No. 20	14.60	3440	0.5	3:60	7:80	0.00	1397	2271	3405
				TYPE IIF[a]					
Control	...	3470	0.50	1:20	3:50	...	1556	2277	3105
No. 1	18.85	3290	0.50	3:45	7:30	0.00	786	1407	2270
No. 1—10%	10.46	...	...	...	...	0.09	1122	1450	2385
No. 1—40%	8.06	...	...	3:40	5:10	0.11	305	466	1008
No. 2	14.40	3590	0.50	...	...	...	...	...	2568
No. 3	18.25	3680	0.52	3:12	6:42	0.02	636	1086	1966
No. 4	20.7	...	...	4:30	8:30	0.02	733	1233	2342
No. 5	18.67	...	...	1:45	5:00	0.02	390	790	1799
No. 6	14.7	3360	0.50	...	...	0.00	843	1297	2150
No. 7	20.2	...	...	...	...	0.14	875	1342	2750
No. 8	12.62	3290	0.48	1:25	5:10	0.20	995	1424	3016
No. 9	16.31	3050	0.5	2:00	4:45	0.02	670	1104	1920
No. 10	15.30	...	...	1:30	4:25	0.05	972	1535	1824
No. 11	16.35	3470	0.50	3:30	7:15	0.02	780	1515	2633
No. 12	13.2	...	...	1:50	4:50	0.04	1111	1418	2300
No. 13	...	...	...	...	...	...	...	...	2590
No. 14	14.55	3480	0.48	4:00	7:30	0.86	1125	1773	3020
No. 15	22.20	...	...	...	...	0.86	1008	1708	3000
No. 16	10.48	3510	0.48	2:45	4:15	0.26	1294	1788	3197
No. 16—40%	16.70	...	...	...	...	1.53	650	1183	1631
No. 17	15.40	3255	0.50	3:15	7:15	0.01	809	1336	2352
No. 17—10%	11.50	...	...	3:20	5:20	0.03	...	1670	2424
No. 17—40%	8.30	...	...	3:15	5:00	0.05	...	602	1543
No. 18	17.89	...	...	3:10	5:47	0.02	891	1275	2190
No. 19	12.8	3290	0.50	...	...	0.00	933	1460	2625
No. 20	16.2	3370	0.50	3:30	7:30	0.02	845	1315	2433

[a] Tests run on mixture of type I portland cement and fly ash; 75 per cent cement and 25 per cent fly ash by weight unless otherwise noted.

Methods of Tests: Proposed Specification for Portland-Fly ash Cement, Sponsoring Committee on Blended Cements, C-1, October, 1951; and applicable sections of the following ASTM requirements: sieve fineness, Method C 115; air permeability fineness, Method C 204; $CaSO_4$, Tentative Specification C 264; compressive strength, Method C 109; 1952 Book of ASTM Standards, Part 3.

TABLE V.—FURTHER RESULTS OF ROUND-ROBIN TESTS EVALUATING THE PROPOSED SPECIFICATION FOR PORTLAND-FLY ASH CEMENT.

Fly Ash	Type IF			Type IIF		
	Autoclave	Mortar Expansion	Air Content per cent by vol	Autoclave	Mortar Expansion	Air Content per cent by vol
Control	...	0.006	...	...	...	...
No. 1	0.068	0.003	...	0.022	...	...
No. 1—10%	...	...	4.2	...	...	6.5
No. 1—40%	...	...	...	...	...	6.0
No. 2	...	...	...	...	...	...
No. 3	0.092	0.003 (—)	7.0	0.032	...	6.0
No. 4	0.066	...	...	0.010	...	...
No. 5	0.100	...	6.5	0.046	...	6.0
No. 6	...	0.000	...	...	...	...
No. 7	0.056	...	...	0.022	...	...
No. 8	...	0.009 (—)	5.0	...	...	...
No. 9	0.074	0.003 (—)	6.5	0.022	...	...
No. 10	...	...	5.5	...	...	6.5
No. 11	0.068	0.003 (—)	...	0.019	...	...
No. 12	...	...	...	...	...	...
No. 13	...	...	. .	...	...	...
No. 14	0.051	0.006 (—)	...	0.006	...	...
No. 15	0.057	...	...	0.005	...	...
No. 16	...	0.000	6.5	...	...	8.5
No. 16—40%	0.005	...	...	0.025 (—)	...	...
No. 17	0.070	0.003 (—)	...	0.012	...	...
No. 17—10%	...	...	5.5	...	...	6.0
No. 17—40%	...	...	4.5	...	...	5.5
No. 18	0.076	...	7.0	0.015	...	7.4
No. 19	...	0.003 (—)	...	...	...	...
No. 20	0.065	0.005 (—)	...	0.014	...	...

Methods of Tests: Proposed Specification for Portland-Fly Ash Cement, Sponsoring Committee on Blended Cements C-1, October, 1951; and applicable sections of the following ASTM requirements: autoclave, Method C 151; air content' Tentative Method C 185; 1952 Book of ASTM Standards, Part 3.

TABLE VI.—RESULTS OF FLY ASH CONCRETE TESTS.

Sample	Loss on Ignition	Average Compressive Strength Results				Flexural Strength	
		7 day, psi	Control, per cent	28 day, psi	Control, per cent	28 day, psi	Control, per cent
Control	...	2235	...	3176	...	658	...
No. 0[a]	...	975	43.7	2088	65.7	...	...
No. 3	12.46	1297	58.2	2297	72.3	535	81.5
No. 4	4.28	1533	68.8	2054	64.7	535	81.5
No. 5	17.97	1378	61.9	2530	79.8	508	77.4
No. 6	4.49	1388	62.2	2520	79.4	485	73.8
No. 8	4.61	1333	59.8	2500	78.8	453	69.0
No. 9	14.50	1418	64.2	2273	71.6	523	79.5
No. 10	6.07	1183	53.1	2513	79.2	505	77.0
No. 12	10.03	1240	54.3	2343	73.4	488	74.2
No 16	1.50	1683	75.8	2756	86.8	528	80.4
No. 17	9.57	1553	68.8	2695	85.2	563	85.6
No. 18	6.51	1462	66.0	2606	82.2	510	77.6
No. 19	4.34	1603	72.0	2983	94.0	550	83.8
No. 20	3.75	1613	72.2	2463	77.7	495	75.5
No. 12a[b]	...	2025	90.8	3430	108.0	...	...
No. 12b[c]	...	713	31.9	1443	45.6	...	...
No. 16a[b]	...	1673	75.0	2957	93.3	...	...
No. 16b[c]	...	1767	78.4	2830	89.4	...	...

NOTE.—Control mix and methods of test in accordance with ASTM Tentative Specification C 226, 1952 Book of ASTM Standards, Part 3. Fly ash concrete mixes made with a 25 per cent replacement by weight of cement unless otherwise noted.

[a] 25 per cent cement taken out—not replaced.

[b] 10 per cent replacement.

[c] 40 per cent replacement.

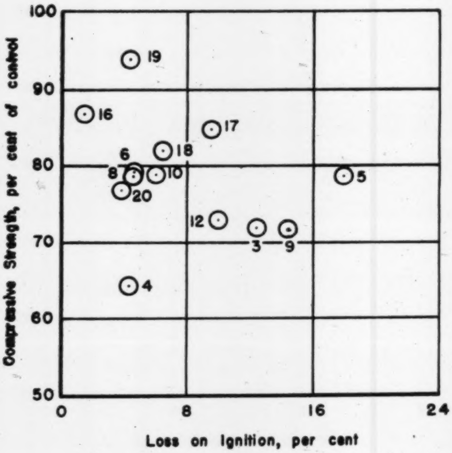

FIG. 8.—Relationship Between Ignition Loss of Fly Ash and Compressive Strength of Concrete.
Age—28 days, cured at 70 F.
See Note in Table VI for mix proportions.

being tested for pozzolanic strength index, methods for preparing samples for chemical analyses, proper conditions for fusion of the sample, and the like.

Round-Robin Tests Run in Accordance with the Proposed Standards.—The results of the chemical analyses are given in Table I. The physical tests are listed in Table II. In order to assist in the interpretation of the physical tests, the use of graphical presentation has been employed (Figs. 1 to 7). Each point is numbered with the sample designation corresponding to that used in Tables I and II. The data represent check values obtained from at least two laboratories, and much of it represents an average value from five laboratories. In general, the agreement between laboratories was good (with the exception of the tests for reduction in mortar expansion).

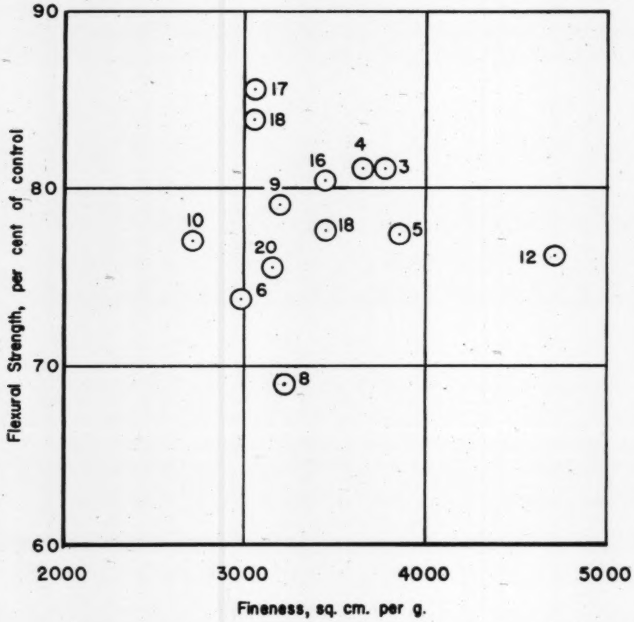

FIG. 9.—Relationship Between Fineness of Fly Ash and Flexural Strength of Concrete.
Age—28 days, cured at 70 F.
See Note in Table VI for mix proportions.

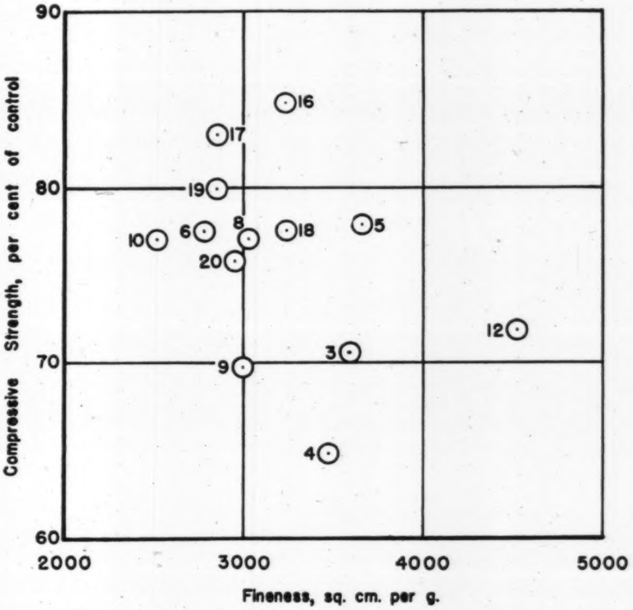

FIG. 10.—Relationship Between Fineness of Fly Ash and Compressive Strength of Concrete.
Age—28 days, cured at 70 F.
See Note in Table VI for mix proportions.

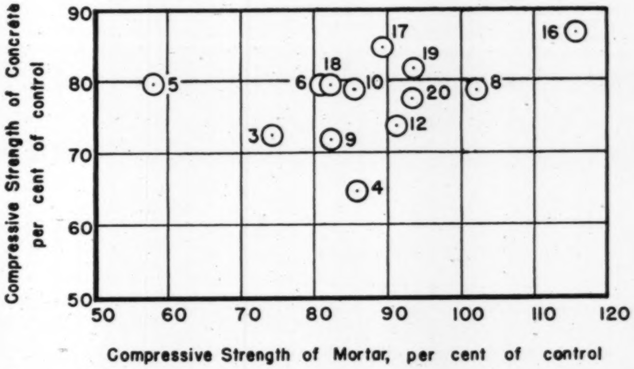

FIG. 11.—Relationship Between the Compressive Strength of Concrete and the Compressive Strength of Mortar.
Concrete aged 28 days, cured at 70 F; mortar aged 28 days, cured at 100 F (pozzolanic strength index).

Tables III, IV, and V summarize the results that have been obtained in connection with a proposed specification for a blended portland-fly ash cement.[6] This study, which was also carried out by the round-robin group, was made on the same samples of fly ash listed in Tables I and II.

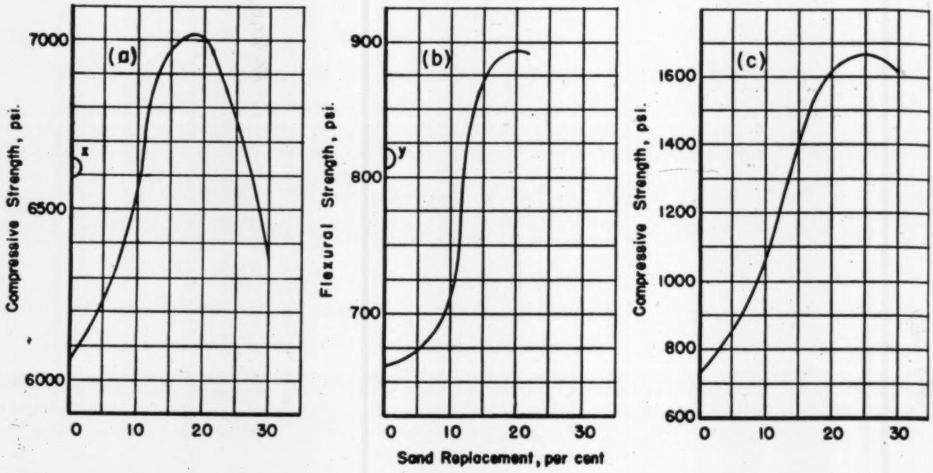

FIG. 12.—Effect of Replacing Sand with Fly Ash on Compressive Strength of Concrete.

(a) Concrete containing 6.2 sacks cement per yard.
Age—28 days, cured at 73 F.
6- by 12-in. cylinders.
Point X represents 7 sack concrete, no fly ash.

(b) Concrete containing 6.25 sacks cement per yard.
Age—28 days, cured at 73 F.
6- by 6- by 24-in. beams.
Point Y represents 7 sack concrete, no fly ash.

(c) Concrete containing 2.6 sack cement per yard.
Age—28 days, cured at 73 F.
6- by 12-in. cylinders.

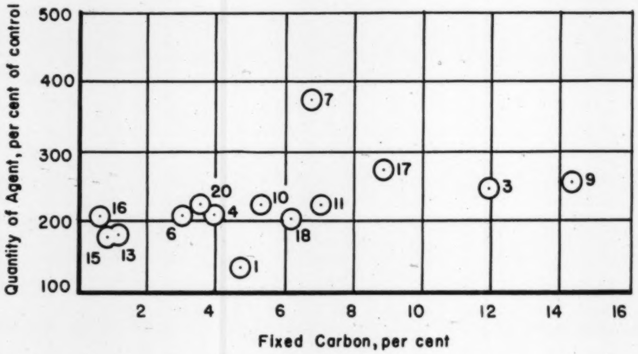

FIG. 13.—Relationship Between Carbon Content of Fly Ash and Amount of Air-Entraining Agent Required in Fly Ash Portland Cement Mortars to Produce 18 per cent Air.

These tests were on mixtures in which 35 per cent of the portland cement was replaced with an equal volume of fly ash.

Supplementary Evaluation Tests.—Many tests and surveys have been made to develop pertinent information relating to the use of fly ash with portland cement compositions. The most important of these considerations are summarized here

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[6] Proposed Specification for Portland-Fly Ash Cement, Sponsoring Committee on Blended Cements of Committee C-1, October, 1951.

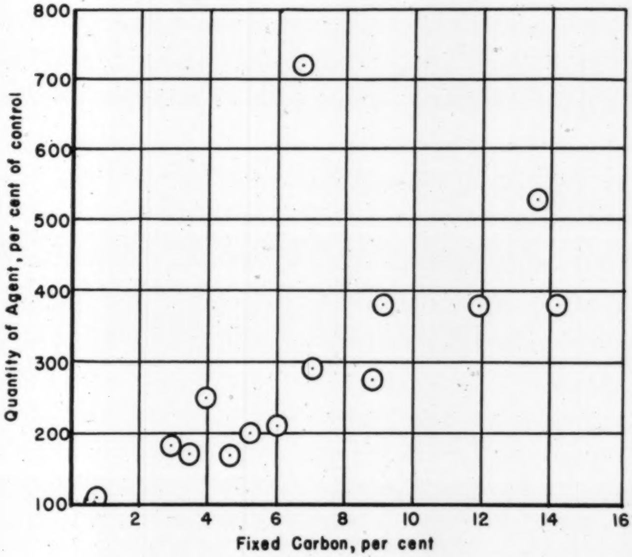

FIG. 14.—Relationship Between Carbon Content of Fly Ash and Amount of Air-Entraining Agent Required in Fly Ash Concrete to Produce 4.5 per cent Air.

The total aggregate for all batches consisted of 50 per cent coarse aggregate (Lincoln sandstone) and 50 per cent fine aggregate (Kaw River sand). The basic mix was designed to have a cement factor of 5.5 sacks per cu yd. In the test mixes, 25 per cent by absolute volume of portland cement was replaced by fly ash.

in condensed form:

(*a*) *Concrete Tests.*—Table VI gives the results obtained from the studies that were made on concrete. Figures 8 to 10 show the concrete results plotted graphically against the information obtained from other studies. Figure 11 shows a comparison that has been made with mortar specimens mentioned previously. Typical results obtained from additions of fly ash to concrete in which the fly ash replaces sand rather than cement are shown in Fig. 12. Concrete tests in which air-entraining agents were employed are listed in the following section.

(*b*) *Effect of Fly Ash on Entrained Air.*—A summary of pertinent information relating to the effect of loss on ignition of fly ash on the air content of both mortars and concrete is given in Figs. 13 to 18 and Table VII. The information on air-entraining agents was supplied by

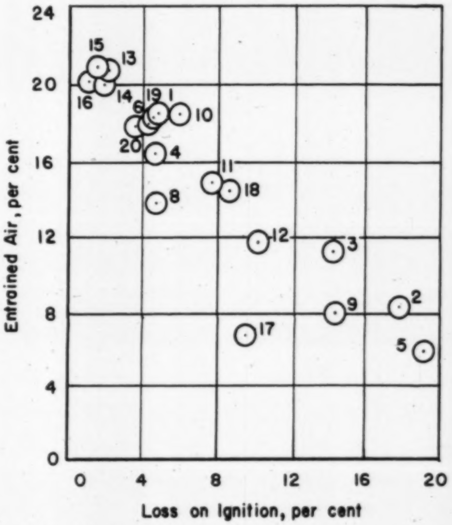

FIG. 15.—Effect of Loss on Ignition of Fly Ash on Entrained Air in Fly Ash Portland Cement Mortars.

ASTM Tentative Method C 185 - 49 T.
25 per cent of portland cement replaced by equal absolute volume of fly ash.

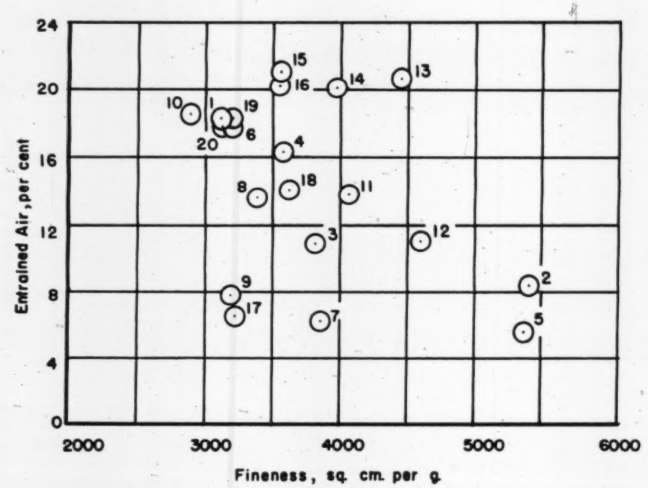

FIG. 16.—Effect of Fineness of Fly Ash on Entrained Air in Fly Ash Portland Cement Mortars.
ASTM Tentative Method C 185 - 49 T.
25 per cent of portland cement replaced by equal absolute volume of fly ash.

five different laboratories, although each laboratory used a different air-entraining agent. Additional information on the use of fly ash with air-entraining agents is included below under Durability.

(*c*) *Pozzolanic Strength Index Test.*—Some of the data presented above (Figs. 1 to 3, 5, 6, and 11) refers to compressive strength mortar tests made at 100 F on specimens cured in sealed cans for 28 days with 35 per cent of the cement replaced by an equal absolute volume of fly ash. When the compressive strength is calculated as the per cent of a control mix which does not contain fly ash, the result is referred to as "pozzolanic strength index" or as given in ASTM Method C 311 - 53 T "strength index." Additional data were obtained from tests run by the round-robin laboratories at higher cement contents and for different conditions of curing; these are presented in Fig. 7. A survey was also made to determine the type container that should be used for this test. For this particular

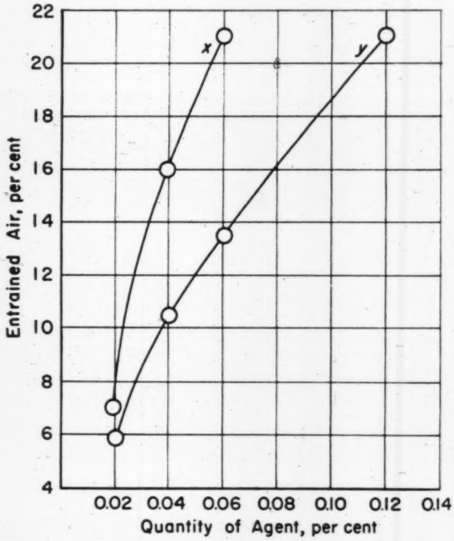

FIG. 17.—Effect of Air-Entraining Agent on Entrained Air in Fly Ash Portland Cement Mortars.

ASTM Tentative Method C 185 - 49 T.
25 per cent of portland cement replaced by equal absolute volume of fly ash.
x = Fly Ash Sample No. 17.
y = Fly Ash Sample No. 5.

investigation, mortar specimens were prepared and cured in tight fitting sealed containers (as specified in ASTM Method C 311 - 53 T), fruit jars, large-sized closed containers, and an open tank which permitted the specimens to be immersed under water. The data for the latter program are not included herein, but the results indicated that the tightly sealed closed containers gave

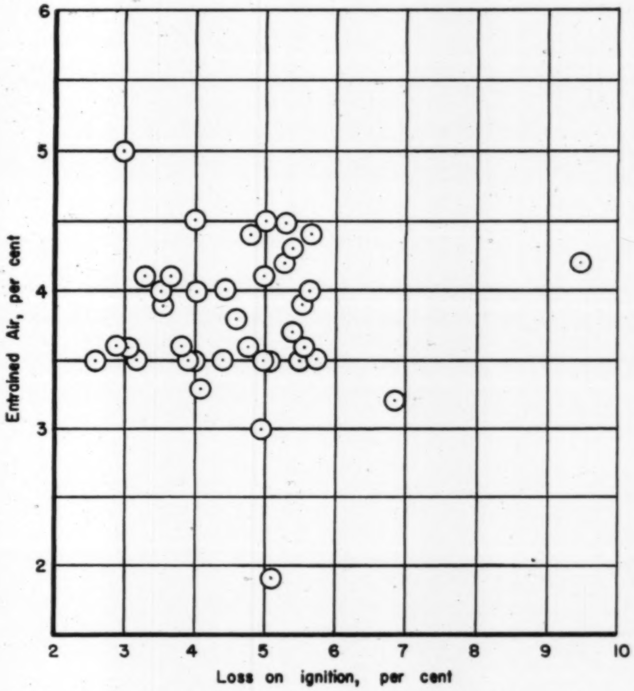

FIG. 18.—Fly Ash Concrete Plant Data Showing Relationship Between Loss on Ignition of Fly Ash and Air Content of Commercially Produced Concrete.

Data supplied by Batch Plant, G. & W. H. Corson, Inc.

TABLE VII.—EFFECT OF AIR-ENTRAINING AGENTS ON FLY ASH CONCRETE.

Sample	Cement, lb per cu yd	Air Entraining Agent, oz per cu yd	Air-Entraining Agent Used	Air-Entraining Agent for 4.5 per cent Air, oz per cu yd	Air, per cent	Slump, in.	Carbon, per cent	Fineness, sq cm per g
Control (A)	540	11.4	Sika Aer	...	9.54	6	...	...
Control (B)	470	5.3	Darex	3.1	8.0	4	...	...
Control (B)	470	2.6	Darex	...	3.8	2	...	...
No. 3	397.5	11.4	Sika Aer	...	5.5	2.5	15.38	...
No. 9	355	12.3	Darex	16.3	3.2	5	14.5	3200
No. 9	355	9.6	Darex	...	2.3	3.5	14.5	3200
No. 10	397.5	11.4	Sika Aer	...	8.9	4	6.04	...
No. 10	355	5.3	Darex	5.5	4.3	3	6.07	2724
No. 16	397.5	11.4	Sika Aer	...	5.3	8	1.32	...
No. 16	355	5.3	Darex	2.4	7.2	3.5	1.5	3443
No. 16	355	2.8	Darex	...	5.6	5	1.5	3443

NOTE.—All fly ash mixes using "Sika Aer" air-entraining agent have replaced 25 per cent of the cement in control mix (A) with equal absolute volume of fly ash.

All fly ash mixes using "Darex" air-entraining agent have replaced 25 per cent of the cement in control mix (B) with equal absolute volume of fly ash.

more consistent results and better agreement between laboratories. For this reason, they have been proposed as the best method for storage of specimens for the elevated temperature test.

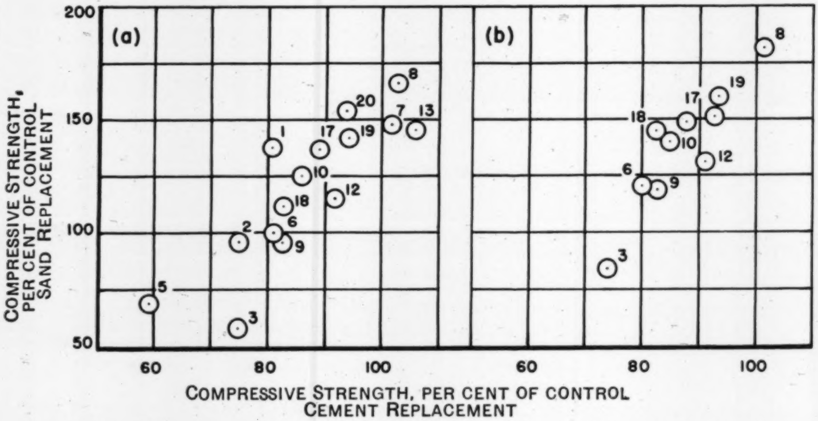

FIG. 19.—Relationship Between Strengths of Cement Replacement Tests (35 per cent) and Sand Replacement Tests (25 per cent).

(*a*) Cement replacement tests cured at 100 F for 28 days. Sand replacement tests cured at 73 F for 7 days.

(*b*) Cement replacement tests cured at 100 F for 28 days. Sand replacement tests cured at 73 F for 28 days.

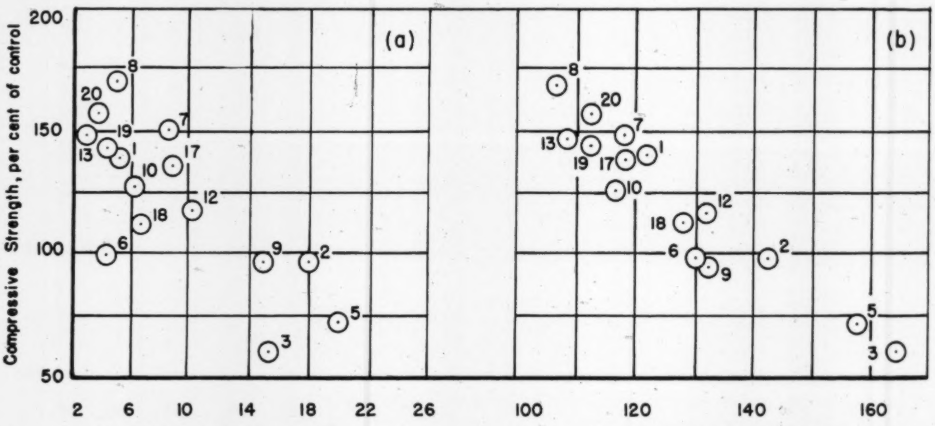

FIG. 20.—Relationship Between the Compressive Strength of Fly Ash-Sand Replacement Tests (25 per cent) Cured at 73 F for 7 Days and (*a*) Loss on Ignition and (*b*) the Amount of Water Required for a Flow of 100.

(*d*) *Compressive Strength Tests Using Fly Ash to Replace Sand in Mortar Cubes.*—In addition to the compressive strength tests mentioned under the pozzolanic strength index test, mortar specimens have been prepared using ASTM Method C 109 - 52[7] except that 25 per cent by weight of the graded Ottawa sand was replaced by an equal weight of fly ash. Compressive strength of the cubes was determined in 7 days and in

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[7] Method of Test for Compressive Strength of Hydraulic Cement Mortars (C 109 - 52), 1952 Book of ASTM Standards, Part 3, p. 119.

28 days. Curing conditions were one day in moist air and the remaining time in water. Figures 19 (*a*) and (*b*) depict graphically the 7- and 28-day results obtained in these tests plotted against the results obtained in the pozzolanic strength index tests. Figures 20 (*a*) and (*b*) show the 7-day results plotted

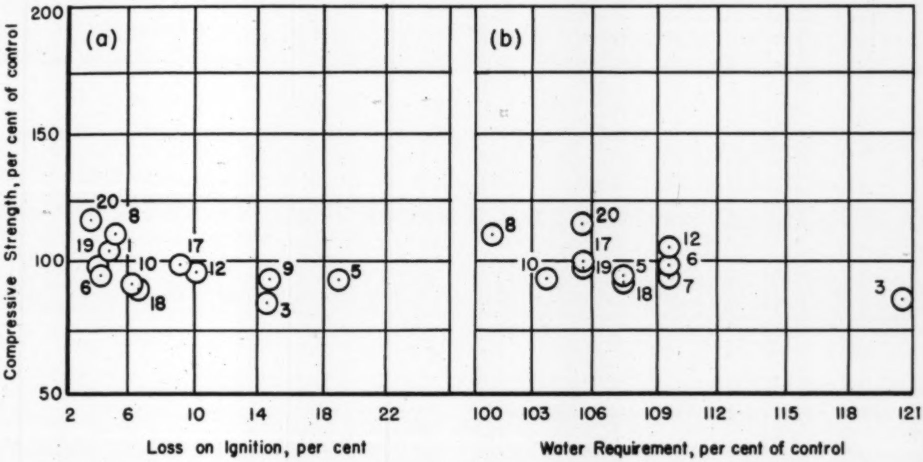

FIG. 21.—Relationship Between Compressive Strengths of Fly Ash Addition Tests (20 per cent) and Loss on Ignition and Water Requirements.
(*a*) Loss on Ignition.
(*b*) Amount of Water Required for a Flow of 100.
Graded Ottawa sand. Aged 7 days and cured at 73 F by immersion in water.

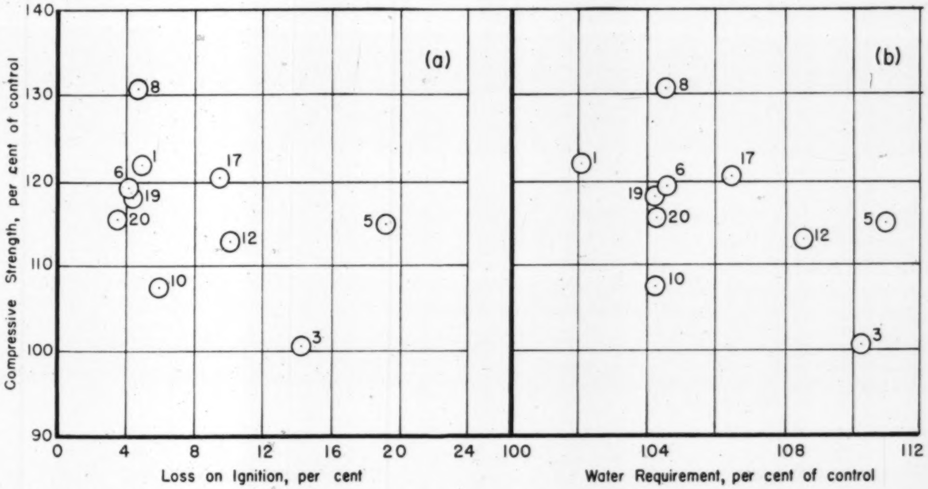

FIG. 22.—Relationship Between Compressive Strengths of Fly Ash Addition Tests (20 per cent) and Loss on Ignition and Water Requirements.
(*a*) Loss on Ignition.
(*b*) Amount of Water Required for a Flow of 100.
Standard Ottawa sand. Aged 7 days and cured at 73 F by immersion in water.

TABLE VIII.—COMPARISON OF TEST METHODS FOR DETERMINING POZZOLANIC ACTIVITY.

Fly Ash	Bureau of Reclamation Test,[a] Reduction in Alkalinity, per cent	Jordan Test,[a,b] $SiO_2 + R_2O_3$, per cent	Davis Test[a]		Minnick Test,[c] 2 by 2 by 2-in. Mortar Cubes, per cent of Control												
			Sealed Cans 130 F		Moist Curing 73 F					Steam Curing 140 F						Autoclave, 100 lb Pressure	
			7 days, psi	28 days, psi	1 day	2 days	7 days	28 days	60 days	6 hr	1 day	3 days	4 days	5 days	6 days	1 hr	2 hr
No. 1	38.97	18.06	525	1270	7.8	95.5	84.2	65.5	136.2	64.5	106.3	108.5	124.5	...	119.0	117.9	126.0
No. 3	32.78	..	590	880	...	...	46.8	72.9	82.8	20.0	...	59.3	57.5	59.1	59.5	22.6	27.4
No. 4	37.11	25.12	...	...	35.6	32.3	47.2	99.0	113.8	42.3	98.5	105.0	108.0	101.0	110.0	73.4	84.0
No. 5	32.4	28.42	...	...	22.8	23.2	26.6	43.8	56.6	49.0	...	58.0	...	61.3	76.5	43.2	34.2
No. 6	23.1	20.48	...	...	31.6	70.6	44.5	80.0	110.2	57.3	89.0	106.0	105.5	102.0	106.0	50.6	52.5
No. 8	61.1	23.61	683	1155	...	...	65.9	109.6	135.0	195.0	145.0	152.0	107.0	145.0	127.0	119.5	136.3
No. 9	...	18.10	...	...	...	...	45.8	68.4	85.3	28.4	72.5	78.3	81.5	90.0	112.0	48.0	43.5
No. 10	44.3	16.30	568	1040	20.2	44.6	70.5	101.5	88.5	73.5	127.5	132.0	135.5	131.0	108.0	49.8	48.3
No. 12	32.8	...	525	1270	21.4	22.3	46.1	72.8	89.0	32.6	79.4	117.0	117.5	115.0	112.5	75.0	76.7
No. 17	37.11	13.59	534	1105	...	...	68.3	101.8	121.0	139.5	...	...	115.0	...	89.5	51.0	55.8
No. 18	39.5	...	...	...	...	...	46.1	93.0	98.3	78.5	88.5	94.0	95.5	85.5	85.0	90.0	89.0
No. 19	49.1	...	...	...	...	...	59.8	70.5	89.0	63.8	154.0	120.0	106.0	99.0	138.0	97.0	102.8
No. 20	30.4	...	683	1225	...	...	21.7	48.8	65.3	126.5	97.0	102.0	103.0	92.5	94.0	87.3	85.9

[a] W. T. Moran and J. L. Gilliland, "Summary of Methods for Determining Pozzolanic Activity," Symposium on Use of Pozzolanic Materials in Mortars and Concretes, p. 109, Appendix A, Am. Soc. Testing Mats. (1950). (Issued as separate publication *ASTM STP No. 99*.)

[b] A 1-g sample of fly ash was refluxed for 30 min in 100 cu cm of 1 *N* NaOH and the dissolved $SiO_2 + R_2O_3$ determined.

[c] Specimens were prepared by mixing equal parts by weight of cement and fly ash with sufficient water to produce a flow of 100. Control specimens made from equal parts of cement and pulverized limestone.

against the ignition loss of the fly ash and also the water requirement of the fly ash.

Compressive strength tests have also been run in which fly ash has been added to the mortar mixes without a corresponding reduction in either cement or sand. A few results are given in Figs. 21 and 22 for 7-day compressive strengths using both graded and Standard (20–30 sieve) Ottawa sand. A number of investigators have also considered this problem from the standpoint of straight additions of fly ash to concrete (**9–13**).[8]

(*e*) *Pozzolanic Activity Tests.*—A number of different methods for measuring pozzolanic activity have been considered by the ASTM committees. These consist of methods proposed by the Bureau of Reclamation, Messrs. Jordan, Davis, Conrow, and the author. Results of cooperative tests are summarized in Tables VIII and IX and in Figs. 23 and 24. (Pertinent information relating to the methods of test are included in the footnotes of the tables and graphs.) The tests included methods in which the fly ash was mixed with portland cement

TABLE IX.—COMPARISON OF VARIOUS POZZOLANIC ACTIVITY DETERMINATION TESTS.

		Sample No. 10	Sample No. 12	Sample No. 8	Sample No. 3
Davis test, psi[a]	7 days	1135	1365	1365	1180
	28 days	2080	2450	2310	1760
Conrow test, psi[b]	7 days	1105	1238	1428	1054
	28 days	1695	2028	2103	1473
Minnick, test, autoclave 2 hr		2178	4364	4528	1239
Pozzolanic strength index, 28 days, per cent of control		102	91	102	74
Loss on ignition, per cent		6.15	10.03	4.72	14.48
Blaine fineness	Porosity	0.49	0.55	0.50	0.56
	cm per g	2913	4545	3372	3780
Water requirement per cent		102.6	104.6	96.3	102.0

[a] See footnote[a] Table VIII.

[b] Specimens consisting of 2 parts by weight of fly ash, 1 part lime, and 8.27 parts standard Ottawa sand were molded and stored in 130 F vapor for 24 hr; removed from molds and stored in 130 F vapor for 48 hr; immersed in 130 F water until 7 days old; and then stored in fog room at 73 F until time of test.

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[8] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 1158.

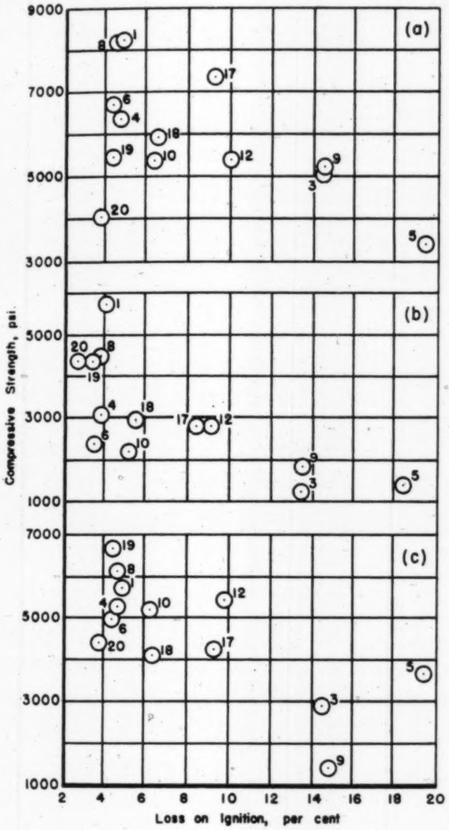

FIG. 23.—Relationship Between Loss on Ignition and Compressive Strength of Fly Ash Portland Cement Mortars (1 to 1 by weight—see Tables VIII and IX).

(*a*) Moist cured at 73 F for 60 days.
(*b*) Autoclaved at 100 psi for 2 hr.
(*c*) Steam cured at 150 F for 6 days.

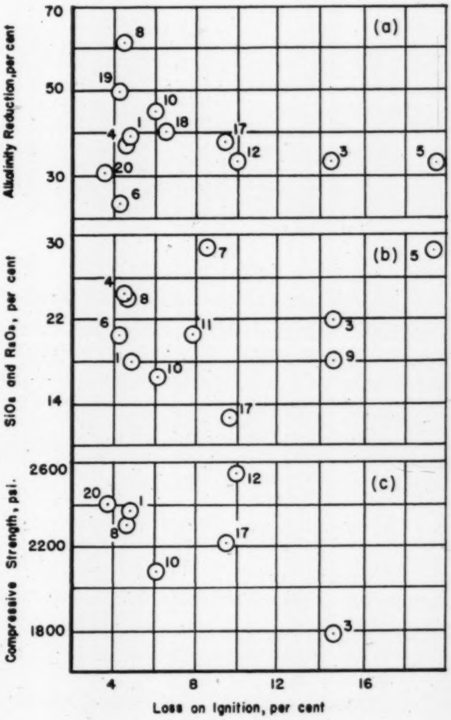

FIG. 24.—Relationship Between Loss on Ignition of Fly Ash and Pozzolanic Activity Tests.

(*a*) Modified Bureau of Reclamation Method.
(*b*) Jordan Method.
(*c*) Davis Test Method using lime-fly ash-sand mortars. Age—28 days, cured at 130 F.

TABLE X.—CHEMICAL CONSTITUENTS OF PULVERIZED-COAL FLY ASH.[a]

Constituents	Fly Ash as a Whole	Retained on Tyler Sieves						
		On No. 35	On No. 100	On No. 150	On No. 200	On No. 325	On No. 400	Through No. 400
Iron as Fe_2O_3, per cent	9.10	4.40	4.50	5.50	6.05	7.90	8.15	9.07
Carbon as C, per cent	10.64	76.30	60.50	31.60	24.75	16.36	13.49	5.20
Magnesium as MgO, per cent	0.83	0.19	0.22	0.24	0.81	0.83	0.86	1.09
Calcium as CaO, per cent	2.38	0.63	0.64	1.17	1.37	1.46	1.48	2.38
Aluminum as Al_2O_3, per cent	26.90	5.71	10.53	20.79	23.43	25.40	26.56	28.31
Sulfur as SO_3, per cent	1.28	0.60	0.70	1.00	0.92	0.86	0.58	1.20
Titanium as TiO_2, per cent	1.35	0.45	0.60	0.95	1.10	1.20	1.30	1.47
Carbonate as CO_2, per cent	0.01	0.03	0.01	0.01	0.02	0.01	0.01	0.004
Silicon as SiO_2, per cent	45.93	8.42	17.46	35.95	39.23	42.21	44.59	48.83
Phosphorus as P_2O_5, per cent	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace
Undetermined, per cent	1.58	3.27	4.84	2.79	2.32	3.77	2.98	2.45

[a] Information obtained from Weinheimer (8).

TABLE XI.—CONCRETE MIXES USED FOR DURABILITY TESTS AND RESULTS OF ABSORPTION TESTS.[a]

Mix	Type Cement	Proportions by Weight, lb					Slump, in.	Absorption Test Results on Concrete, per cent	
		Cement	Fly Ash	Fine Aggregate	Coarse Aggregate	*W/C* per Sack Cement		24 hr	28 days
No. 1	Portland type I	376	...	1500	1960	276.89	4	4.7	5.3
No. 2	Interground 80% portland type I, 20% fly ash	291.2	72.8	1500	1960	276.89	4⅛	5.1	5.6
No. 3	80% portland type I, 20% fly ash	300.8	75.2	1498	1958	272.22	4	4.9	5.5
No. 4	70% portland type I, 30% fly ash	263.2	112.8	1498	1960	271.13	4	4.9	5.5
No. 5	Air-entraining portland	376	...	1474	1926	266.88	4⅛	4.7	5.3
No. 6	80% air-entraining portland, 20% fly ash	300.8	75.2	1488	1945	264.71	4⅛	4.4	5.1
No. 7	70% air-entraining portland, 30% fly ash	263.2	112.8	1490	1949	263.88	4	4.8	5.3
No. 8	Portland type I	376	...	1500	1960	276.89	4	...	...
No. 9	80% portland type I, 20% fly ash	300.8	75.2	1498	1958	272.22	4	...	...
No. 10	70% portland type I, 30% fly ash	263.2	112.8	1498	1960	271.13	4	...	...

[a] Results of tests by the Robert W. Hunt Co. (Engineers) through the courtesy of the Commonwealth Edison Co.

TABLE XII.—RESULTS OF FREEZING AND THAWING TESTS.[a]

Mix[b]	After 120 Cycles		After 150 Cycles	
	Change in Surface Dry Weights, per cent	Compressive Strength, psi	Change in Surface Dry Weights, per cent	Compressive Strength, psi
No. 1	−0.16	2938	−0.46	2787
No. 2	−0.07	3086	−0.18	2900
No. 3	−0.12	4055	−0.22	3866
No. 4	+0.01	3371	−0.02	3465
No. 5	−0.24	2730	−0.43	2612
No. 6	+0.03	3727	+0.01	3626
No. 7	+0.12	2539	+0.07	1961

Mix	Thawing Agent	After 30 Cycles			After 60 Cycles		
		Difference in Surface Dry Weights, per cent	Difference in Dry Weights, per cent	Scaling of Top Surface, per cent	Difference in Surface Dry Weights per cent	Difference in Dry Weights, per cent	Scaling of Top Surface, per cent
No. 8	Thawing salts	0.03	0.59	None	0.30	0.25	None
	Calcium chloride	−0.58	−0.67	18.74	−4.91	−6.34	51.05
No. 9	Thawing salts	0.02	0.44	None	0.20	−0.44	None
	Calcium chloride	0.03	0.27	None	0.19	−0.76	1.95
No. 10	Thawing salts	0.02	0.13	None	−0.08	−0.60	None
	Calcium chloride	0.04	0.17	None	0.30	−0.35	0.43

NOTE.—Specimens 1 to 7 cured at 70 F in a moist chamber for 28 days; dried to constant weight at 100 F; cooled to room temperature and weighed; immersed in water at 70 F for 48 hr and the surface dry weights recorded. Specimens then subjected to 30 cycles of repeated freezing (0 F for 16 hr) and thawing (for 8 hr). After the final cycle, specimens immersed in water at 70 F for 48 hr; the surface dry weights recorded; redried at 100 F; cooled to room temperature; weighed dry; and the test results determined.

Specimens 8 to 10 were standard cured at 70 F in a moist chamber for 3 months; immersed in water for 48 hr; then surface dried and weighed.

[a] Results of tests by the Robert W. Hunt Co. (Engineers) through the courtesy of the Commonwealth Edison Co.

[b] Proportions for these mixes are listed in Table XI.

and also with hydrated lime. Very little is known regarding the chemistry of pozzolanic reactions. It is quite possible that other constituents than the silica are involved when lime combines with fly ash. Results obtained from the publication of C. M. Weinheimer (8) are given in Table X, which shows the typical chemical characteristics of the various size fractions for fly ash.

(*f*) *Durability.*—Many durability tests have been run on concrete containing fly ash. Typical examples of the information that is available is given in Tables XI and XII. It will be noted that the data include information on both blended and interground materials with and without an air-entraining agent. R. E. Davis *et al.* have investigated this problem quite thoroughly with particular regard to the influence of ignition loss on the performance of the concrete (2, 3, 4, 5).

TABLE XIII.—RESULTS OF INTERGRINDING FLY ASH WITH PORTLAND CEMENT.[a]

Mix	Fineness Lea-Nurse Method, sq cm per g	Compressive Strength, Average Values of 3 Samples			
		7 days	28 days	6 months	1 yr
1 part ground clinker (ground with 4% gypsum), 2.90 parts Ottawa sand	3590	3543	4757	4878	5780
1 part ground clinker (ground with 5% gypsum and 10% fly ash), 2.90 parts Ottawa sand	..	3925	5572	6075	7005
1 part ground clinker (ground with 5% gypsum and 20% fly ash), 2.90 parts Ottawa sand	5545	4215	4863	5752	6880

NOTE.—Curing conditions: 7 days in moist closet at 70 F at 90 per cent relative humidity, then in laboratory air for remainder of test.

[a] Results of cooperative tests by the Central Laboratory of the Lehigh Portland Cement Co. and by the G. & W. H. Corson Laboratory.

(*g*) *Effect of Intergrinding.*—Tables XIII and XIV give some of the results relating to the difference between blending and intergrinding of fly ash and portland cement. This information is of more importance in the preparation of a blended portland-fly ash cement than in a specification for fly ash as an admixture to concrete. In the latter case, the fly ash need not be used to replace cement but may become an integral part of the aggregate content of the concrete. Table XV gives the results of another investigation showing the effect of intergrinding of fly ash for different grinding time periods.

TABLE XIV.—RESULTS OF INTERGRINDING FLY ASH WITH PORTLAND CEMENT.[a]

	Medusa, Portland Cement Type I	Medusa Cement with 20 per cent Fly Ash Interground
Fineness Test:		
Passing No. 325 sieve, per cent	90.7	96.9
Wagner Tubidimeter, Specific Surface, sq cm per g	1735	2230
Specific gravity	3.140	3.045
Soundness Test:		
Autoclave expansion, per cent	−0.19	−0.11
Time of Setting (determined by Gillmore needle):		
Normal consistency	24.5	24.0
Initial set, hr:min	3:30	3:25
Final set, hr:min	5:25	5:20
Compressive Strength (2-in. cubes):		
Mix, cement to graded standard sand	1:2.75	1:2.75
Flow, per cent	103.1	103.1
Strength, lb per sq in.	...	...
Cure conditions: 1 day in moist closet at 70 F at 90% relative humidity then immersed in water at 70 F until age specified:		
1 day	947	1331
3 days	2234	2483
7 days	3483	3817
28 days	5467	5867
Tensile Strength, (standard briquettes):		
Mix, cement to standard sand	1:3	1:3
Strength, lb per sq in.		
Age at test, days:		
1	178	235
3	280	387
7	447	483
28	472	523

[a] Results of tests by the Robert W. Hunt Co. (Engineers) through the courtesy of the Commonwealth Edison Co.

(*h*) *Drying Shrinkage.*—Comparison of shrinkage as related to ignition loss for different fly ash proportions using the round-robin fly ash samples is shown in Fig. 25. Additional information on this

TABLE XV.—RESULTS OF INTERGRINDING FLY ASH WITH PORTLAND CEMENT.[a]

Sieve Size	(Clinker) Material Before Pulverizing, As Received		After 1 hr of Pulverizing		After 2 hr of Pulverizing		After 3 hr of Pulverizing		After 4 hr of Pulverizing		After 5 hr of Pulverizing	
	Cumulative Per Cent Retained	Per Cent Passing	Cumulative Per Cent Retained	Per Cent Passing	Cumulative Per Cent Retained	Per Cent Passing	Cumulative Per Cent Retained	Per Cent Passing	Cumulative Per Cent Retained	Per Cent Passing	Cumulative Per Cent Retained	Per Cent Passing
8	0.0	100.0	0.0	100.0	0.0	100.0	0.00	100.00	0.00	100.00	0.00	100.00
30	100.0	0.0	25.5	74.5	2.2	97.3	0.06	99.94	0.02	98.98	0.01	99.99
50	100.0	0.0	51.0	49.0	16.4	83.6	2.40	97.60	0.15	99.85	0.05	99.95
100	100.0	0.0	69.4	30.6	43.1	56.9	26.52	73.48	13.45	86.55	5.53	94.47
200	100.0	0.0	82.3	17.7	63.2	36.8	51.50	48.50	41.20	58.80	33.15	66.85
325[b]	99.6	0.4	82.7	17.3	66.8	33.2	56.50	43.50	48.00	52.00	42.82	57.18

[a] Results of tests by the Robert W. Hunt Co. (Engineers) through the courtesy of Commonwealth Edison Co.
[b] Tested in accordance with ASTM Method C 115, 1952 Book of ASTM Standards, Part 3.

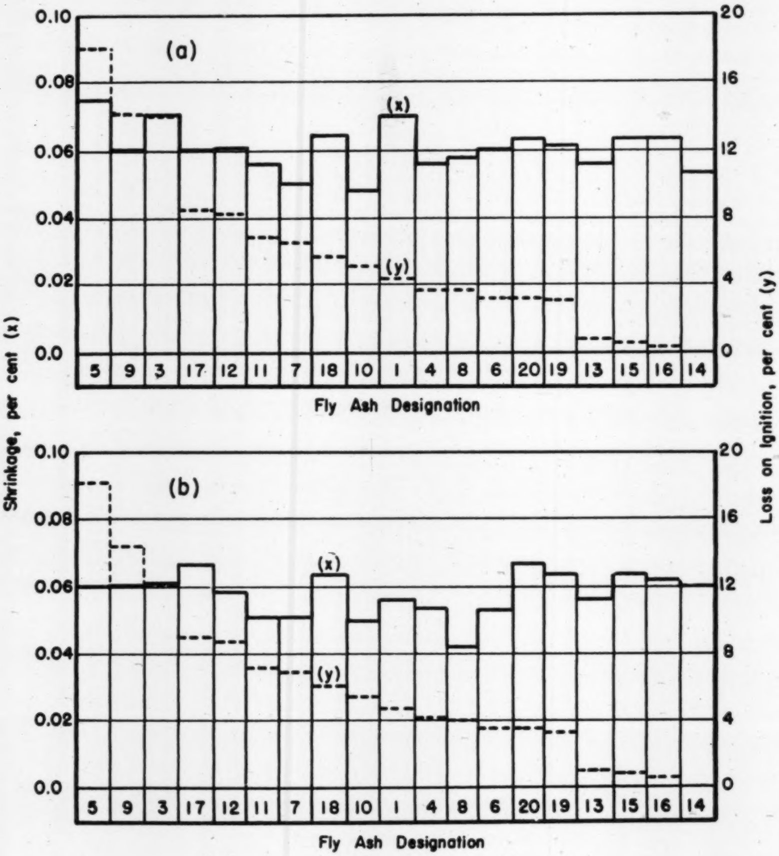

FIG. 25.—Comparison of Shrinkage in Laboratory Air with per cent Loss on Ignition (Age—28 days).

Data supplied by Dept. of Applied Mechanics, Kansas State College.

(*a*) Mix data for three 1- by 1- by 11-in. bars.
262.5 g standard cement.

$$87.5 \times \frac{\text{sp gr fly ash}}{\text{sp gr cement}} = \text{grams fly ash.}$$

962 g Ottawa sand.
Curing: 24 hr in moist room followed by 6 days soaking.

(*b*) Mix data for three 1- by 1- by 11-in. bars.
262.5 g standard cement.

$$175 \times \frac{\text{sp gr fly ash}}{\text{sp gr cement}} = \text{grams fly ash.}$$

$$962 - \frac{87.5 \times \text{sp gr sand}}{\text{sp gr cement}} = \text{grams Ottawa sand.}$$

Curing: 24 hr in moist room followed by 6 days soaking.

subject is also available in the publications of R. E. Davis *et al.* (2, 3, 4, 5).

Corps of Engineers, U. S. Army Tests:

In the early part of 1951, the Corps of Engineers obtained four samples of fly ash representing several different conditions of fineness and ignition loss. The investigations that are being carried out are not yet complete, but preliminary data covering some of the work are presented.

The chemical analyses and physical tests on the fly ash samples and on pastes and mortars made with these fly ash samples are summarized in Tables XVI, XVII, and XVIII.

TABLE XVI.—RESULTS OF FLY ASH TESTS BY THE CORPS OF ENGINEERS—CHEMICAL ANALYSIS, PER CENT.

	Sample No. AD-3	Sample No. AD-7	Sample No. AD-8	Sample No. AD-9
Moisture loss	0.20	0.19	0.17	0.26
SiO_2	47.2	47.4	38.2	44.9
Al_2O_3	19.5	34.0	25.7	34.0
Fe_2O_3	18.2	9.0	16.3	6.5
Mn_2O_3	0.07	0.04	0.16	0.04
P_2O_5	0.23	0.14	0.26	0.51
CaO	5.3	2.3	3.9	2.3
MgO	1.2	1.2	0.9	0.4
Sulfide sulfur	0.05	0.00	0.13	0.04
SO_3	2.2	0.7	0.60	0.34
Ignition loss	0.8	3.9	12.2	7.9
Insoluble residue	70.4	79.4	64.9	76.8
Na_2O (Gravimetric)	0.69	...	0.16	...
K_2O (Gravimetric)	1.16	...	0.53	...
Total as Na_2O (Gravimetric)	1.45	...	...	...
Na_2O (Photometric)	1.62	0.38	0.63	0.30
K_2O (Photometric)	1.98	1.75	1.02	1.72
Total as Na_2O (Photometric)	2.92	1.53	1.30	1.43
Total carbon	0.43	3.17	11.13	7.22

TABLE XVII.—RESULTS OF FLY ASH TESTS BY THE CORPS OF ENGINEERS, PHYSICAL ANALYSIS.

	Sample No. AD-3	Sample No. AD-7	Sample No. AD-8	Sample No. AD-9
Specific gravity	2.48	2.36	2.43	2.26
Fineness, sq cm per g:				
Air permeability	3565	2940	2945	4205
Fisher method	3337	2855	2715	3960
Nitrogen adsorption	7900	16 000	24 700	30 200
Hydrometer	7030	5960	5050	5045
Per cent finer than No. 325 sieve	93.5	87.7	85.8	81.5
Size range microns (microscope)	0.5 to 1000	0.5 to 1000	1 to 2000	1 to 3000
Predominant size range, microns (microscope)	1 to 10	3 to 13	4 to 20	3 to 14
Per cent finer than No. 200 sieve (dry)	95.5	92.8	93.6	85.1
Constituents by microscope examination, per cent:				
Glass	81	75	51	70
Cristobalite	Trace	Trace	Trace	Trace
Carbon	1	15	35	21
Quartz, feldspar, iron oxide, etc.	18	10	14	9

Bureau of Reclamation Tests:

In June, 1952, the Bureau of Reclamation submitted a report summarizing results obtained in its laboratory. Eighty-one samples of fly ash were considered in this study, which was directed in large part to an investigation of fly ash of high pozzolanic strength that was being considered by the Bureau for use in mass concrete.

Much of the data supplied by the Bureau of Reclamation is given in condensed form in Table XIX and in Figs. 26 to 28

Other Contributors:

The literature on fly ash as related to concrete is growing rapidly. Most of this published information was considered by the working subcommittees. An excellent bibliography may be found in a recent publication by R. E. Morgan of the Bureau of Mines (1). Particular reference should be made to the work of R. E Davis who ran thousands of tests on fly ash (2, 3, 4, 5). Also of importance was a paper presented to the ASTM by H. A. Frederick (6) and, more recently, a paper by R. C. Mielenz (7). In addition to these studies, a number of investigations have been concerned with the question of the measurement of pozzolanic activity. A very brief résumé of some of these data is included in the results presented above.

DISCUSSION

In order to assist in evaluating the data, a summarizing Table XX has been prepared. This table lists the physical and chemical requirements that have been proposed as specification requirements for fly ash, but it does not include the requirements for portland-fly ash cement. In the last column of Table XX, an analysis is made of the results of tests on 20 fly ash samples used in the round-robin tests, and the fly ash samples that do not meet the requirements of the proposed specification for fly ash are listed.

For the methods of test finally adopted, good reproducibility was obtained between the laboratories in all of the tests except the reduction in mortar bar expansion. The Bureau of Reclamation, which originated this test, has found that it can obtain reproducibility in its own laboratory, but members of the round-robin test group had difficulty in accomplishing this. Apparently the skill of the test engineer is a factor with this test.

Considerable attention has been given to the test for pozzolanic strength index. Elevated temperature seems to be desirable for this test as with it good indications are secured in 28 days of the relative contribution to strength made by the fly ash as pozzolanic material. The test results indicate that good correlation may be expected between the pozzolanic strength tests made in mortar cubes cured at 70 F for shorter periods of time. This may result in the development of a more rapid test based on strength alone. It is suggested that the reason for the good correlation between the tests run at 100 F (cement replacement) and those at 73 F (sand replacement) is basically

TABLE XVIII.—RESULTS OF FLY ASH MORTAR TESTS BY THE CORPS OF ENGINEERS.

	Portland Cement Type II Control	Fly Ash Sample					
		No. AD-3			No. AD-7	No. AD-8	No. AD-9
Per cent of cement replaced by solid volume	0	30	45	60	45	45	45
Bleeding rate, ml per sq cm per sec × 10^{-6} (W/C = 0.4)[a]	61	69	78	85	99	91	71
Bleeding capacity, ml per cu cm × 10^{-3} (W/C = 0.4)[a]	17	28	43	45	40	34	25
Initial set, hr:min (Gillmore)[b]	3:45	2:25	2:35	3:10	4:40	4:35	5:20
Final set, hr:min (Gillmore)[b]	5:45	9:00	9:35	8:25	7:45	7:35	8:45
Compressive strength, psi[c]							
3 days	1610	2090	1810	1150	1010	915	960
7 days	2600	2790	2125	1585	1525	1290	1385
28 days	4635	5385	4660	3200	3125	2775	2810
Autoclave expansion, per cent[d]	0.11	0.04	0.02	0.04	0.01	0.01	0.02
Normal consistency, per cent[e]	25.0	23.2	22.8	23.0	27.0	30.2	31.8
Air content of mortar, per cent[f]	5.8	4.9	3.5	3.1	2.9	2.2	3.5

[a] The ratio of the volume of water to solid volume of cement plus fly ash is the same as the ratio of volume of water to volume of portland cement in the paste made with 100 per cent portland cement.

[b] Gillmore setting time tests were made on pastes using ASTM Method C 191 – 49, with 500 grams of cement or equal solid volume of cement plus fly ash and the amount of water determined by ASTM Method C 187 to give normal consistency.

[c] Compressive strength tests determined in accordance with ASTM Method C 109.

[d] Autoclave expansion test determined in accordance with ASTM Method C 151.

[e] Normal consistency determined on pastes in accordance with ASTM Method C 187.

[f] Air content determined on mortar made in accordance with Paragraph F-66 of Federal Specifications SS-C-158b using standard Ottawa sand and a flow of 90 to 110.

TABLE XIX.—RESULTS OF TESTS BY THE BUREAU OF RECLAMATION.

Bureau of Reclamation Reference Number	SiO_2, per cent	Al_2O_3, per cent	MgO, per cent	SO_3, per cent	Ignition loss, per cent
8511	46.10	23.18	0.98	2.32	1.45
8728	48.38	21.72	1.25	2.93	2.47
8729	47.56	28.50	1.11	1.12	2.59
8730	43.24	15.12	1.23	1.72	2.04
8735	51.26	30.38	1.18	0.48	3.11
9270	47.61	29.10	1.47	2.12	0.56
9874	48.38	21.72	1.25	2.93	2.47
9875	...	...	...	...	1.12
9905	...	...	...	...	2.63
9978	...	...	...	...	2.22
9980	...	...	...	...	12.08
9981	...	...	...	...	9.91
9982	...	...	...	...	22.63
A-223	...	...	...	...	4.88
A-259	...	...	...	...	9.37
A-260	...	...	...	...	8.22
A-261	...	...	...	...	13.06
A-262	...	...	...	...	12.07
A-263	...	...	...	...	7.16
A-264	...	...	...	...	11.27
A-463	41.83	19.18	1.29	2.16	5.56
A-464	46.44	20.89	1.48	2.49	1.84
A-767	45.10	20.21	1.37	2.52	2.91
A-806	...	...	...	...	2.95
A-832	...	...	...	...	2.44
A-860	...	...	...	...	1.39
A-861	...	...	...	...	1.70
A-862	...	...	...	...	1.67
A-863	...	...	...	...	2.34
A-864	...	...	...	...	1.64
A-865	...	...	...	...	0.89
A-866	...	...	...	...	0.96
A-867	...	...	...	...	1.27
A-976	41.30	25.30	0.90	1.02	6.19
A-1038	...	...	...	...	4.47
A-1108	...	...	...	...	1.34
A-1234	37.55	20.31	Trace	1.80	19.51
A-1243	34.90	22.31	Trace	3.19	16.27
A-1247	35.84	19.70	1.28	12.19	10.66
A-1254	43.69	22.54	1.20	2.37	3.52
A-1255	44.42	22.66	1.61	2.08	9.06
A-1256	38.10	19.14	1.28	8.22	8.88
A-1257	37.77	23.41	0.97	0.81	4.32
A-1274	37.43	21.25	1.33	1.11	6.35
A-1319	39.37	18.90	1.06	2.25	15.21
A-1322	39.49	28.19	0.72	0.60	14.66
A-1326	38.07	21.81	1.59	1.60	10.18
A-1351	45.82	29.49	0.83	0.35	5.84
A-1375	42.33	34.04	0.85	0.33	7.32
A-1379	43.68	19.03	1.13	1.56	1.59
A-1409 A-1410 A-1411 A-1414 A-1415 A-1416	49.58	24.80	1.18	0.51	3.89
A-1412 A-1413 A-1417 A-1418	40.35	16.72	1.13	0.67	6.12
A-1444	44.61	17.10	1.40	1.07	5.45
A-1460	51.88	18.58	1.45	0.66	4.54
A-1474 A-1475 A-1476 A-1477 A-1478 A-1479	36.00	19.04	0.86	0.75	5.36
M-1157	35.04	18.63	3.00	0.60	5.77
M-1158	35.39	18.79	3.00	0.64	5.66
M-1159	36.03	19.02	3.00	0.54	6.83
M-1160	38.82	19.25	1.25	0.68	6.44

TABLE XIX.—*Concluded.*

Bureau of Reclamation Reference Number	SiO_2, per cent	Al_2O_3, per cent	MgO, per cent	SO_3, per cent	Ignition loss, per cent
M-1161	36.10	18.29	1.16	0.55	5.94
M-1162	33.88	20.08	1.07	0.70	4.35
M-1163	...	...	...	...	5.76
M-1164	...	...	...	...	5.40
M-1165	...	...	...	...	5.68
M-1166	...	...	...	...	5.88
M-1178	38.07	22.36	0.07	1.17	5.45

NOTE.—Tests run in accordance with Federal Specification SS-C-158b.

the effect of the water requirement on the compressive strength of the test specimens. Figures 6 and 20(*b*) both show good correlation between compressive strength and water requirement for each series of mortar mixtures. Figures 19(*a*) and (*b*), which show the relationship between compressive strength for cement replacement and sand replacement, merely reflect the influence of the water-cement ratio on the strength of the specimens. This would seem to indicate that the water requirement has more bearing on these results than do factors such as pozzolanic activity, fineness of the fly ash, etc.

The data shown in Table XVIII indicate that with a low-carbon, high-fineness fly ash some improvement in strength is obtained at early ages. For all other samples, the replacement of cement with fly ash results in a decrease in strength. It is possible that part of the early strength shown for sample No. AD-3 is a result of pozzolanic activity. It will be noted that the strength characteristics follow, in general, the pattern indicated by the microscopic examination, that is, the higher the glass phase, the higher the value of compressive strength.

The data obtained by the Bureau of Reclamation give somewhat less indication of a definite pattern when plotted graphically than the data obtained in the round-robin test series. An example of this may be noted by comparing Fig.

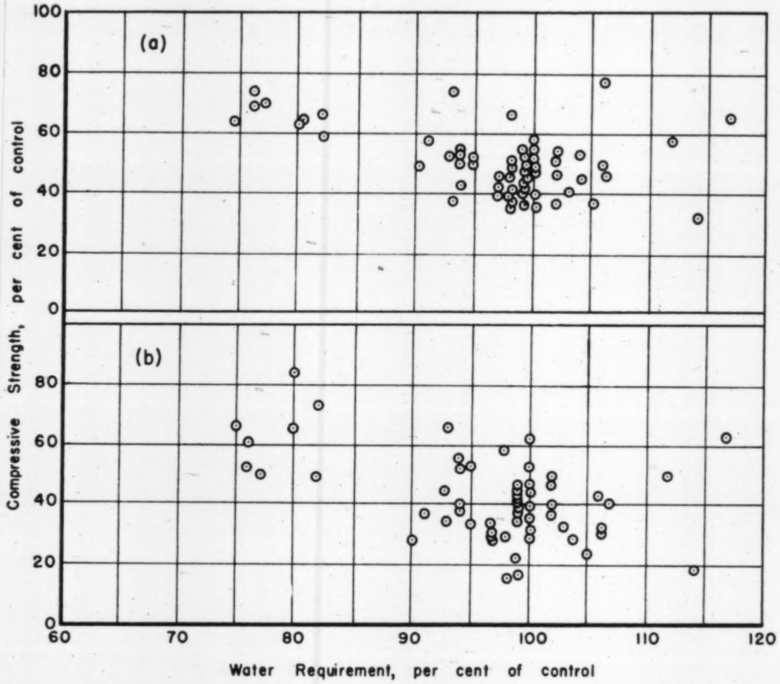

FIG. 26.—Relationship Between Water Requirement and Compressive Strength of Fly Ash Portland Cement Mortar Specimens.

(*a*) Age—28 days, cured at 73 F. (*b*) Age—28 days, cured at 100 F.

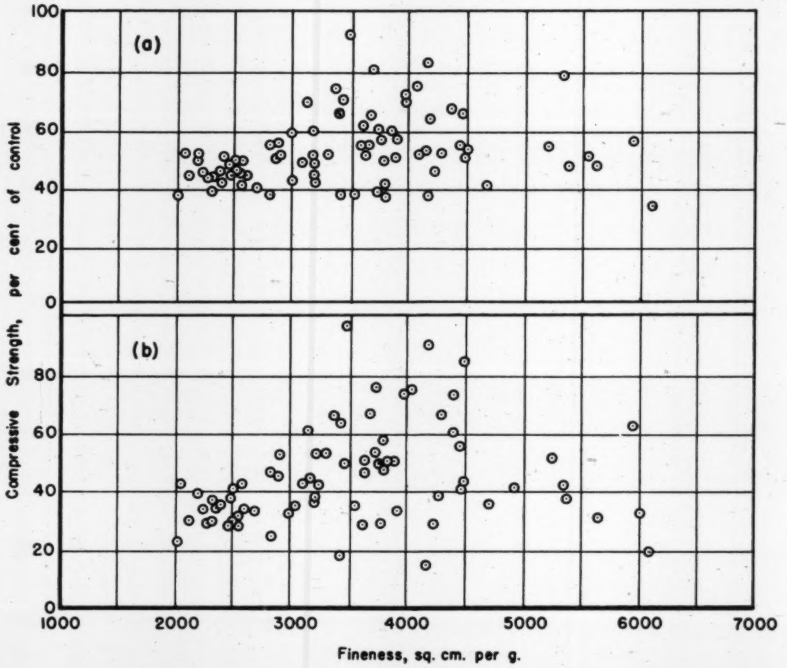

FIG. 27.—Relationship Between Fineness and Compressive Strength of Fly Ash Portland Cement Mortar Specimens.

(*a*) Age—28 days, cured at 73 F. (*b*) Age—28 days, cured at 100 F.

6 with Figs. 26(*a*) and (*b*) in which water requirement is plotted against the compressive strength obtained from specimens cured at 73 and 100 F. The reason for this may be partly due to the choice of control which was used in determining the relative strength values. In the case of the round-robin tests, a new control was prepared for each mix that was made. It is understood that this was not done in all cases with the Bureau of Reclamation tests.

Figures 28(*a*) and (*b*) indicate that substantially higher compressive strengths might be realized for fly ash having ignition loss of less than 3 per cent. The samples plotted in the low ignition loss area of the graphs were obtained primarily from one supplier of fly ash. This is the same material which gave the improved strength in the tests run by the Army Engineers as shown in Table XVIII. As stated, the higher strengths of this material may actually result from other properties possessed by this particular source of fly ash.

The question of the advisability of running tests on concrete rather than on mortar has frequently been raised. The data show that there is not a very satisfactory correlation between concrete and mortar compression tests (Fig. 11). However, the mortar tests appear to be more sensitive to the type of fly ash that is used, particularly with respect to loss on ignition (Figs. 1 and 8). This would appear to justify a mortar test requirement for the fly ash specification.

In connection with the relationship between air content and ignition loss of fly ash, the data are somewhat conflicting. A greater variation is evident in air

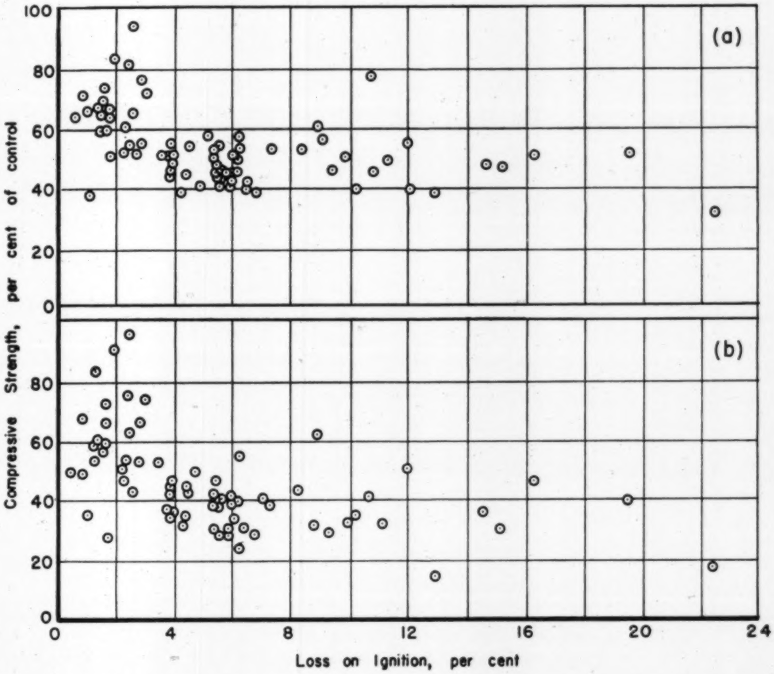

FIG. 28.—Relationship Between Loss on Ignition and Compressive Strength of Fly Ash Portland Cement Mortar Specimens.

(*a*) Age—28 days, cured at 73 F.
(*b*) Age—28 days, cured at 100 F.

content for the concrete specimens than for the mortar specimens where a relatively small amount of fly ash is incorporated into the mixture. Data obtained from field use of fly ash, however, where larger quantities (of the order of 200 lb per cu yd) are used (Fig. 18) show that much less variation is obtained in the air content of concrete in which different types of fly ash are employed. It is indicated in this case that the additional quantity of air-entraining agent is substantially less than would be shown by the tests made on laboratory specimens with lower quantities of fly ash.

TABLE XX.—ANALYSIS OF FLY ASH SPECIMENS USING AS A BASIS THE REQUIREMENTS THAT HAVE BEEN PROPOSED AS A SPECIFICATION FOR FLY ASH FOR USE AS ADMIXTURE FOR PORTLAND CEMENT CONCRETE.

	Proposed Limits	Specimens Not Passing Limits
CHEMICAL REQUIREMENTS		
SiO_2 (minimum), per cent	40.0	2, 3, 7, 8, 9, 10
Al_2O_3 (minimum), per cent	15.0	All pass
$SiO_2 + Al_2O_3$ (minimum), per cent	50.0	All pass
MgO (maximum), per cent	3.0	All pass
SO_3 (maximum), per cent	4.0	All pass
Loss on ignition(maximum) per cent	12.0	2, 3, 5, 9
Moisture (maximum), per cent	3.0	All pass
Exchangeable alkalies expressed as Na_2O, (maximum), per cent	1.5	5, 7, 12, 13, 15, 16, 17, 18
PHYSICAL REQUIREMENTS		
Blaine fineness (minimum), sq cm per g	2800	All pass
Contribution to compressive strength used as a replacement of standard Ottawa sand, 25 per cent by weight of the Standard Ottawa sand:		
Per cent of control at 7 days	115.0	2, 3, 5, 6, 9, 18
Per cent of control at 28 days	125.0	2, 3, 5, 6, 9, 18
Pozzolanic strength index		
Per cent of control at 28 days (minimum)	85.0	1, 2, 3, 5, 6, 9, 10, 11, 18
Per cent of 28-day strength, at 90 days (minimum)	100	3
Drying shrinkage (maximum), per cent	0.10	All pass
Reduction of mortar expansion (minimum), per cent	60.0	1, 2, 3, 4, 7, 9, 11
Autoclave expansion (minimum), per cent	0.50	Not tested
Water requirement (maximum), per cent of control	103.0	2, 3, 5, 9, 12
Air entraining agent required		
Number of times the amount of admixture required for control (ASTM Method C 185 mortar)	5.0	Not tested

The studies on pozzolanic activity which are summarized in Tables VIII and IX and Figs. 23 and 24 show that there is a considerable variation in the activity of different fly ash materials. Where lime is used in the test, the methods employed by Davis or by Conrow would seem to give good indication of the performance of the fly ash. Where portland cement is used with fly ash, the autoclave test (Fig. 23(*b*)) shows interesting possibilities.

Figure 25 shows that very little relationship exists between the shrinkage of fly ash and the loss on ignition. The fly ash samples in this figure are arranged in the order of decreasing loss on ignition reading from left to right.

A correlation is indicated between sulfur trioxide content and compressive strength as shown in Fig. 3(*d*) and the effect of magnesium oxide as shown in Fig. 5. Most of the sulfur content of fly ash is present as soluble sulfate. The magnesium oxide content is found as part of the glassy phase, and there is no evidence of periclase or other crystalline forms of magnesium compounds.

It will be noted that when any two of the properties of fly ash are compared no attempt has been made to hold the other chemical or physical properties constant. Therefore, the relationships which might exist between variables are difficult to interpret accurately. Attempts have been made to establish clear trends between two variable properties while holding all other variable properties constant, but considerably more data are needed before any more informative analysis along these lines can be made than that indicated above.

There are many unanswered questions that still face the engineer in connection with the use of fly ash in concrete, just as there are many unanswered questions in connection with concrete itself. Some of these problems are perplexing and difficult to solve and will be resolved only through many years of research and experience. However, the background of fly ash in concrete has now reached a point in technical achievement where the engineer can receive assurance that specifications such as are being promulgated by ASTM committees are acceptable for general use.

Acknowledgment:

There has been a considerable amount of effort put into these studies by a large group of test engineers, and it is virtually impossible to give adequate recognition to all of the contributors. The author wishes to express his sincere thanks to the many individuals and organizations who have cooperated in these studies for their valuable suggestions which have been made a part of this report.

The following producers of fly ash supplied the ASTM committees with samples of fly ash representing a cross-section of much of the material available in this country:

Consolidated Gas Electric Light and Power Co. of Baltimore
Baltimore , Md.

Potomac Edison Co.
Hagerstown, Md.

Public Service Electric and Gas Co.
Newark, N. J.

Philadelphia Electric Co.
Philadelphia, Pa.

Atlantic City Electric Co.
Atlantic City, N. J.

Detroit Edison Co.
Detroit, Mich.

Chicago Fly Ash Co.
Chicago, Ill.

Monongahela Power & Light Co.
Rivesville, W. Va.

The following individuals and laboratories cooperated in the fly ash round-robin tests:

Mr. Norman Withey
Chicago Fly Ash Co.
Chicago, Ill.

Mr. C. M. Weinheimer
Mr. J. R. Wilde
Mr. Edward Hines
Detroit Edison Co.
Detroit, Mich.

Dr. E. W. Guernsey
Mr. J. A. McComas
Dr. N. H. Skau
Consolidated Gas Electric Light and Power Co. of Baltimore
Baltimore , Md.

Mr. Harry A. Frederick
Mr. Kenneth B. Cox
Public Service Electric and Gas Co.
Testing Laboratory
Maplewood, N. J.

Prof. C. H. Scholer
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Kansas State College
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Mr. W. H. Bolger
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Chicago, Ill.

Mr. Leonard Bean
National Bureau of Standards
Washington, D. C.

Mr. H. K. Cook
Mr. Bryant Mather
Mr. Leonard Pepper
Waterways Experiment Station
Jackson, Miss.

Dr. L. John Minnick
G. & W. H. Corson, Inc.
Plymouth Meeting, Pa.

REFERENCES

(1) R. E. Morgan, "Utilization of Fly Ash," *Information Circular 7635*, U. S. Bureau of Mines, U. S. Department of Interior, June, 1952.

(2) R. E. Davis, "Use of Pozzolans in Concrete," *Journal*, Am. Concrete Inst., Vol. 21, No. 5, January, 1950, pp. 377–384.

(3) R. E. Davis, H. E. Davis, and J. W. Kelly, "Weathering Resistance of Concretes Containing Fly Ash Cements," *Journal*, Am. Concrete Inst., Vol. 12, January, 1941, pp. 281–293.

(4) R. E. Davis, "Discussion of the Thorson and Nelles Article on Pulverized-Coal-Ash Utilization," *Mechanical Engineering*, Vol. 61, June, 1939, pp. 475–476.

(5) R. E. Davis, R. W. Carlson, J. W. Kelly, and H. E. Davis, "Properties of Cements and Concretes Containing Fly Ash," *Journal*, Am. Concrete Inst., Vol. 8, May–June, 1937, pp. 577–612.

(6) H. A. Frederick, "Application of Fly Ash for Lean Concrete Mixes," *Proceedings*, Am. Soc. Testing Mats., Vol. 44, pp. 810–820 (1944).

(7) R. C. Mielenz, *et al.*, "Chemical Tests for Alkali Reactivity of Pozzolans," *Proceedings*, Am. Soc. Testing Mats., Vol. 52, pp. 1128–1144 (1952).

(8) C. M. Weinheimer, "Evaluating Importance of the Physical and Chemical Properties of Fly Ash in Creating Commercial Outlets for the Material," *Transactions*, Am. Soc. Mechanical Engrs., Vol. 66, No. 6, August, 1944, pp. 551–561.

(9) J. S. Nelles and A. A. Sellke, "Fly Ash in Concrete," *Proceedings*, National District Heating Assn., pp. 199–205 (1940).

(10) F. R. McMillan and T. C. Powers, "Classification of Admixtures as to Pozzolanic Effect by Means of Compressive Strength of Concrete," *Journal*, Am. Concrete Inst., Vol. 9, November–December, 1937, pp. 129–143.

(11) C. P. Derleth, discussion of "Classification of Admixtures as to Pozzolanic Effect by Means of Compressive Strength of Concrete," *Journal*, Am. Concrete Inst., Vol. 9, March–April, 1938, pp. 144-1–144-4. See reference 10.

(12) J. S. Nelles, discussion of "Weathering Resistance of Concretes Containing Fly Ash Cements," *Journal*, Am. Concrete Inst., Vol. 12, June, 1941, pp. 296-1–296-2. See reference 3.

(13) "Fly Ash Makes Better Concrete," Chicago District Electric Generating Corp., Chicago, Ill.

DISCUSSION

Mr. Bryant Mather.[1]—The paper includes data from a number of sources; a few of the data were derived from a program that is being conducted by the Corps of Engineers. Tables XVI, XVII, and XVIII give the results of chemical tests, physical tests, and tests of pastes and mortars. These deal with samples of fly ash from four sources selected to represent the range of composition and properties of fly ashes that have been considered for use in concrete. Mr. Minnick has suggested that some additional discussion would be appreciated, particularly of the effect of fly ashes on air-entrainment in concrete.

Our investigation has concerned the use of fly ash and a variety of other mineral admixtures as replacements for part of the portland cement in concrete. The work on concrete involves laboratory mixtures made with crushed limestone aggregate graded up to the $\frac{3}{4}$-in. size. Five different cements were used. Concrete mixtures were proportioned for each of two fixed water-cement ratios. When part of the portland cement was replaced by another material, the water-cement ratio was maintained by keeping a constant weight of water to a given total solid volume of portland cement plus replacement material. The replacements were made on a solid volume basis. The mixtures were controlled to a given consistency as measured by the remolding test.

The accompanying Table XXI indicates certain effects of a 45 per cent replacement of each of two cements by each of the four fly ashes in concrete mixtures of the two water-cement ratios. The top half of the tabulation indicates the amount of air-entraining admixture (neutralized vinsol resin) required to

TABLE XXI.—AIR-ENTRAINING ADMIXTURE DEMAND AND DRYING SHRINKAGE OF FLY ASH CONCRETE.

All values are averages of results of three rounds of tests.

Type of Cement	Water-Cement Ratio	Amount of Neutralized Vinsol Resin Required to Produce 6.0 ± 0.5 per cent Air in Concrete with ¾-in. Aggregate, ml per cu yd				
		No Fly Ash	45 per cent of Cement Replaced by Fly Ash			
			Fly Ash I	Fly Ash II	Fly Ash III	Fly Ash IV
II	0.5	485	348	647	1214	886
II	0.8	265	242	410	688	500
I[a]	0.5	248	248	531	1026	732
I[a]	0.8	146	162	339	601	428
		Drying Shrinkage of Concrete after Storage at 50 per cent RH and 73.4 F to 180-Days Age, as Thousandths of a per cent of 14-Day Length				
II	0.5	58	52	56	62	55
II	0.8	56	46	46	47	45
I[a]	0.5	56	49	56	58	55
I[a]	0.8	46	45	38	45	50

[a] High-alkali.

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[1] Engineer, Concrete Division, Waterways Experiment Station, Corps of Engineers, Jackson, Miss.

produce 6 ± 0.5 per cent air in the freshly mixed concrete. From 146 to 485 ml of neutralized vinsol resin per cubic yard of concrete were required to achieve the desired air content when no fly ash was used. This variation is a function of the characteristics of the portland cements used and the water-cement ratio of the concrete, since all other factors, such as workability, aggregate grading, temperature, and consistency, were kept constant. With fly ash I and type II cement less air-entraining admixture was required than when no fly ash was used.

TABLE XXII.—UNIFORMITY STUDIES ON FLY ASH USED IN CONJUNCTION WITH THE CONSTRUCTION OF SEWAREN GENERATION STATION OF THE PUBLIC SERVICE GAS AND ELECTRIC CO.

Sample	Specific Gravity	Moisture Content, per cent	Fineness, 325 Sieve, Per Cent Retained	Sample	Specific Gravity	Moisture Content, per cent	Fineness, 325 Sieve, Per Cent Retained
No. 1	2.50	0.195	8.55	No. 31	2.55	0.174	7.39
No. 2	2.48	0.198	7.73	No. 32	2.50	0.227	7.32
No. 3	2.54	0.179	8.47	No. 33	2.68	0.277	4.69
No. 4	2.60	0.141	6.41	No. 34	2.65	0.249	4.29
No. 5	2.52	0.203	8.29	No. 35	2.64	0.243	2.75
No. 6	2.70	0.207	8.51	No. 36	2.58	0.235	3.55
No. 7	2.75	0.204	8.17	No. 37	2.50	0.242	5.42
No. 8	2.61	0.203	8.28	No. 38	2.45	0.183	6.53
No. 9	2.63	0.387	8.66	No. 39	2.57	0.155	4.02
No. 10	2.50	0.196	13.91	No. 40	2.56	0.175	5.00
No. 11	2.60	0.187	7.61	No. 41	2.57	0.155	5.35
No. 12	2.63	0.176	6.51	No. 42	2.51	0.212	5.58
No. 13	2.49	0.263	9.79	No. 43	2.66	0.199	3.42
No. 14	2.56	0.183	9.33	No. 44	2.51	0.160	7.50
No. 15	2.51	0.159	8.01	No. 45	2.49	0.194	8.96
No. 16	2.52	0.154	7.06	No. 46	2.56	0.198	9.05
No. 17	2.54	0.141	8.71	No. 47	2.56	0.188	6.09
No. 18	2.53	0.183	8.96	No. 48	2.52	0.182	7.82
No. 19	2.53	0.176	8.62	No. 49	2.59	0.199	8.96
No. 20	2.55	0.188	8.43	No. 50	2.66	0.214	6.06
No. 21	2.69	0.200	6.41	No. 51	2.50	0.217	6.96
No. 22	2.62	0.212	7.45	No. 52	2.52	0.246	8.44
No. 23	2.63	0.200	6.97	No. 53	2.47	0.182	5.65
No. 24	2.65	0.241	3.59	No. 54	2.60	0.301	5.98
No. 25	2.63	0.251	3.93	No. 55	2.58	0.320	5.91
No. 26	2.63	0.189	6.89				
No. 27	2.53	0.231	8.63				
No. 28	2.63	0.201	6.75				
No. 29	2.69	0.182	6.58				
No. 30	2.55	0.188	6.95				

NOTE.—This data through the courtesy of Harry A. Frederick, Public Service Gas and Electric Co., Maplewood, N. J. These tests were run over a period of one year. Approximately 40,000 cu yd of concrete were placed. Slump, 3 to 6 in. Five sacks of portland cement and 100 lb of fly ash per cu yd of concrete.

With fly ash III a great increase in amount of air-entraining admixture was required when 45 per cent of the cement was replaced by fly ash.

The accompanying Fig. 29 indicates the relation between amount of neutralized vinsol resin required and the carbon

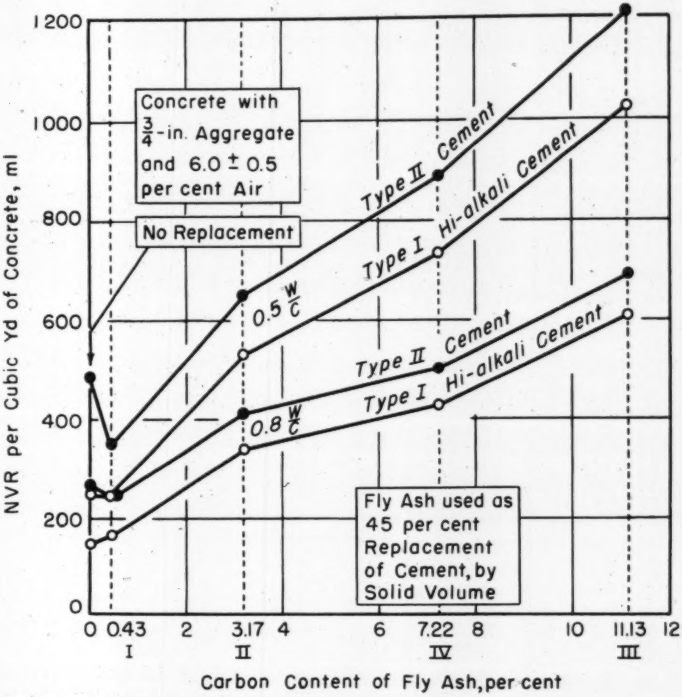

FIG. 29.—Relation of Carbon Content of Fly Ash to Amount of Air-Entraining Admixture Required for 6.0 per cent Air in $\frac{3}{4}$-in. Aggregate Concrete Made with Two Cements at Two Water-Cement Ratios with 45 per cent Replacement of Cement by Fly Ash.

TABLE XXIII.—FLY ASH UNIFORMITY TESTS—POWER PLANT PRODUCTION VALUES.

Date of Sampling	Loss on Ignition, per cent			Specific Gravity			Blaine Surface Area, sq cm per g		
	Station No. 1	Station No. 2	Station No. 3	Station No. 1	Station No. 2	Station No. 3	Station No. 1	Station No. 2	Station No. 3
11-24-53	6.53	8.80	...	2.22	2.32	...	3655	3850	...
12-2-53	6.70	6.25	12.73	2.30	2.29	2.47	3635	3875	3510
12-8-53	10.97	7.03	12.95	2.29	2.30	2.44	4455	4235	3770
12-14-53	7.88	9.48	12.51	2.29	2.32	2.46	4110	5000	4060
12-22-53	8.52	5.93	12.87	2.32	2.51	2.37	5760	4050	3920
12-29-53	7.17	8.18	13.25	2.29	2.40	2.37	4050	4760	3480
Average	7.96	7.61	12.86	2.28	2.36	2.42	4278	4295	3748
Deviation									
Minimum	18.0%	17.9%	2.7%	2.6%	3.0%	2.1%	15.0%	10.3%	7.1%
Maximum	30.8%	24.6%	3.0%	1.8%	6.4%	2.1%	34.6%	16.4%	8.3%

NOTE.—Presented by E. W. Guernsey, Consolidated Gas Electric Light and Power Co., Baltimore, Md.

TABLE XXIV.—FLY ASH UNIFORMITY TESTS AS DETERMINED AT A CENTRAL MIX CONCRETE PLANT.[a]

Sample	Loss on Ignition	Specific Gravity		Blaine Fineness		Air-Entrainment Mortar Test	
		ρ	Deviation, per cent[b]	sq cm per g	Deviation, per cent[b]	NVX,[c] per cent, Based on Weight of Cement	Deviation, per cent[b]
No. 1	6.06	2.47	...	3365	...	0.030	...
No. 2	6.27	2.43	0.82	3317	1.42	0.027	10.0
No. 3	6.48	2.55	4.08	3891	16.46	0.022	21.4
No. 4	5.21	2.45	1.21	3537	0.37	0.029	11.5
No. 5	7.48	2.56	3.23	3265	7.43	0.026	3.7
No. 6	6.19	2.48	0.40	3599	3.57	0.030	11.1
No. 7	5.52	2.50	0.40	3124	10.28	0.023	14.8
No. 8	5.63	2.50	0.40	3288	4.50	0.030	11.1
No. 9	4.31	2.46	1.20	3391	0.93	0.027	0.0
No. 10	6.75	2.43	2.41	3849	12.58	0.033	22.2
No. 11	4.93	2.56	3.23	3258	5.92	0.021	25.0
No. 12	4.50	2.56	2.81	2557	25.93	0.020	33.3
No. 13	4.97	2.64	5.18	2570	23.87	0.020	23.1
No. 14	4.23	2.55	1.59	2416	25.52	0.027	3.5
No. 15	4.35	2.53	0.40	2851	8.94	0.032	23.1
No. 16	5.30	2.56	1.59	2924	5.37	0.032	23.1
No. 17	4.26	2.45	3.16	2915	3.57	0.025	7.4
No. 18	4.65	2.58	2.38	2849	5.09	0.028	3.7
No. 19	4.21	2.69	6.32	2503	15.39	0.023	14.8
No. 20	3.67	2.64	3.12	2570	10.42	0.027	3.9
No. 21	4.99	2.59	0.39	2815	2.70	0.030	15.4
No. 22	4.38	2.59	0.39	2721	0.89	0.029	11.5
No. 23	3.71	2.68	3.87	2476	0.87	0.027	0.0
No. 24	3.85	2.62	1.16	3188	17.87	0.033	17.9
No. 25	4.72	2.46	5.02	2505	9.92	0.038	31.0
No. 26	5.43	2.50	1.57	3587	30.58	0.036	24.1
No. 27	5.80	2.56	0.78	3037	7.96	0.030	0.0
No. 28	7.14	2.53	2.32	3106	9.95	...	...
No. 29	6.43	2.55	1.54	3159	10.80	...	...
No. 30	7.20	2.51	2.34	3033	3.85	0.033	10.0
No. 31	6.84	2.45	4.30	3695	19.81	...	...
No. 32	6.42	2.49	2.35	3021	0.98	0.036	16.1
No. 33	6.58	2.46	0.31	3319	7.72	0.034	6.3
No. 34	6.41	2.50	0.40	3150	0.48	...	...
No. 35	6.00	2.50	0.00	2799	11.45	...	...

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[a] Fly ash shipped from one source, sampled from trucks, in accordance with sampling requirements of proposed specification.

[b] Deviation determined in accordance with proposed specification requirement, each value being compared with the average of the values obtained on the 10 preceding samples or with the average of all preceding samples when less than 10 in number.

[c] Neutralized vinsol resin.

content of the fly ash. Fly ash I, which showed less air-entraining admixture requirement when it was used to replace type II cement, contains 0.43 per cent carbon, and fly ash III, which caused the largest increase in air-entraining admixture requirement when it was used, contains 11.13 per cent carbon. The maximum amount of admixture required with no fly ash (485 ml) is not greatly different from the minimum amount (601 ml) required for a 45 per cent replacement of fly ash of 11.13 per cent carbon in concrete made with a different cement and water-cement ratio. It is therefore suggested that these data, while they do indicate the very marked effect on air-entraining admixture demand as a function of the carbon content of the fly ash, serve also to point up what has been so often emphasized in the past, that very many other factors affect the amount of air-entraining admixture required in concrete.

TABLE XXV.—INVESTIGATION OF THE AMOUNT OF AIR-ENTRAINING AGENT REQUIRED TO PRODUCE AIR-ENTRAINED CONCRETE USING DIFFERENT SOURCES OF FLY ASH.

Cement Content, lb per cu yd	Loss on Ignition, per cent	Fly Ash Content, lb per cu yd	Sand, lb per cu yd	Gravel, lb per cu yd	Air Content, per cent	Amount[a] of Air-Entraining Agent	Slump, in.	Water, lb per cu yd
				SAMPLE A				
376........	...	0	1393	1812	5.2	4.2	2.5	231
470........	...	0	1334	1815	5.5	4.2	3.5	228
564........	...	0	1242	1813	5.7	4.2	4.7	239
564........	3.5–4.5	150	733	2127	4.4	11.6	[b]	261
				SAMPLE B				
376........	...	0	1393	1812	5.2	4.2	2.5	231
470........	...	0	1334	1815	5.5	4.2	3.5	228
564........	...	0	1242	1813	5.7	4.2	4.7	239
				SAMPLE C				
376........	...	0	1473	1814	5.1	0.043	3.8	241
470........	...	0	1374	1815	4.5	0.040	4.4	249
564........	...	0	1286	1814	4.9	0.049	4.7	251
564........	7–8	150	753	2126	5.2	0.623	[b]	271

[a] With Samples A and B, Darex was used, and amounts are in fluid ounces per cubic yard. With Sample C, vinsol resin was used, and amounts are in pounds per cubic yard.

[b] Slump approximately the same as control.

NOTE.—Presented by C. M. Weinheimer, The Detroit Edison Co., Detroit. Mich.

On the lower part of Table XXI, data are given on drying shrinkage. It has been suggested that the drying shrinkage of concrete is markedly influenced by the carbon content of the fly ash. An inspection of these data, bearing in mind that fly ash III has more than 11 per cent carbon and fly ash I less than ½ per cent carbon, will indicate that a significant increase in drying shrinkage as a function of the carbon content of the fly ash is not revealed.

MR. L. JOHN MINNICK (*author*).—Several discussions have been forwarded to the author and since these include data that are pertinent to recent developments in connection with the preparation of a fly ash specification, a brief condensation of some of the information has been prepared. The accompanying Tables XXII, XXIII, and XXIV give results of tests reported by different investigators relating to the question of uniformity of fly ash. The tables include tests that were run in accordance with the requirements in the proposed specification for fly ash.[2]

Where air-entrained concrete is specified, the specification includes an air-entraining admixture requirement and also includes an air-entraining requirement for mortar specimens under the uniformity requirement section. Table XXIV includes data obtained on mortar specimens prepared in accordance with the proposed revision of ASTM test method C 311 - 53 T[3] with samples of fly ash obtained from ready-mixed concrete operation. Another investigation that has been reported recently dealing with the use of fly ash in air-entrained concrete is summarized in Table XXV.

An effort is now under way to establish a new cooperative test program, the purpose of which will be to develop information in regard to certain chemical and physical requirements in the specification which have been subject to discussion regarding their necessity and the suitability of the limits proposed. Individuals who would like to make suggestions in connection with the proposed test program should communicate with the chairman of Subcommittee III-h on Methods of Testing and Specifications for Admixtures of ASTM Committee C-9 on Concrete and Concrete Aggregates.

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[2] This specification has now been adopted as ASTM Tentative Specification for Fly Ash for Use as an Admixture for Portland-Cement Concrete (C 350 - 54 T), 1954 Supplement to Book of ASTM Standards, Part 3, p. 256.

[3] The revised method has been accepted as Tentative Methods of Sampling and Testing Fly Ash for Use as an Admixture for Portland-Cement Conrete (C 311 - 54 T), 1954 Supplement to Book of ASTM Standards, Part 3, p. 267.

A RAPID ACCELERATED TEST FOR CEMENT-AGGREGATE REACTION*

By C. H. Scholer[1] and G. M. Smith[2]

Synopsis

This paper describes an accelerated method of test for predicting the deterioration of concrete caused by cement-aggregate reaction. A period of 90 days from time of casting specimens is sufficient to discriminate between concretes having undesirable expansion and those having little or no expansion. The expansion data from the rapid accelerated exposure, referred to as exposure 10, show a very good correlation with the expansion of concretes subjected to the well-known wetting-and-drying exposure (**1**),[3] referred to as exposure 2. To substantiate the merit of exposure 10, data are presented showing the close correlation between the relative expansion of concretes subjected to 7.5 yr of outside weathering and concretes subjected to exposure 2.

Cement-aggregate reaction as referred to in this paper is not restricted to the alkali-aggregate reaction but refers to the physical and perhaps chemical reactions, or a combination of both, which cause the expansion that is usually accompanied by "map cracking." This type of cracking should not be confused with surface checking, shrinkage cracking, or cracking due to settlement and loads.

Rapid Accelerated Exposure—Exposures 10 and 10-1

Exposure 10 consists of placing the concrete beams, standing on end, in a tank where they are exposed to a continuous spray of water at a rather low velocity but of such intensity and distribution that water is continually flowing over all surfaces of the beams. One complete cycle consists of gradually changing the temperature of the water from 68 to 130 F and then back to 68 F. A cycle is complete in 45 min. During one cycle the approximate temperature at the center of a 3 by 4 by 16-in. beam changes from 74 to 122 F and back to 74 F. The temperature change is obtained automatically and is gradual so as to avoid a "shock effect," although as indicated in Fig. 3 the rate of temperature change sometimes exceeds 200 F per hr. The controls are set to obtain 32 cycles per day, 224 cycles per week. The apparatus shown in Figs. 1 and 2 provides space for testing 60 3 by 4 by 16-in. specimens simultaneously. Tap water is supplied to the system as shown in Fig. 2 through a $\frac{3}{4}$-in. water line supplying 7$\frac{1}{10}$ gal per min. Heating is by means of steam supplied at 44 psi through a mixing valve shown in Fig. 2. No refrigeration is supplied as the tap water temperature averages

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13–18, 1954.

[1] Professor of Applied Mechanics, Kansas State College, Manhattan, Kans.

[2] Assistant Professor of Engineering Mechanics, University of Nebraska, Lincoln, Neb.

[3] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 1177.

62 F. Steam is admitted to the system at 45-min intervals, heating the water which is added to the tank to not over 130 F. When this temperature is reached, the steam is throttled to prevent excessive heating. The period of heating is regulated so that but little throttling is necessary. No refrigeration other than the cold water supplied is used. Water is continuously circulated by means of the circulating pump at the rate of $20\frac{1}{2}$ gal per min through the three tubes shown in Fig. 2. Tubes are of brass, 1 in. in outside diameter, each tube having five rows of 100 holes each in the length of 4 ft and 1 in. These holes were drilled with a No. 49 drill and all holes are in the lower 120 deg of the tube. The circulating pump maintains a pressure of 4 psi on the header. Water is wasted continually at approximately the same rate the tap water is added plus the steam condensed during the heating cycle. The spray tank installation is shown in Figs. 1 and 2. Exposure 10 was developed under a cooperative research program between the Portland Cement Assn. and the Engineering Experiment Station of Kansas State College.

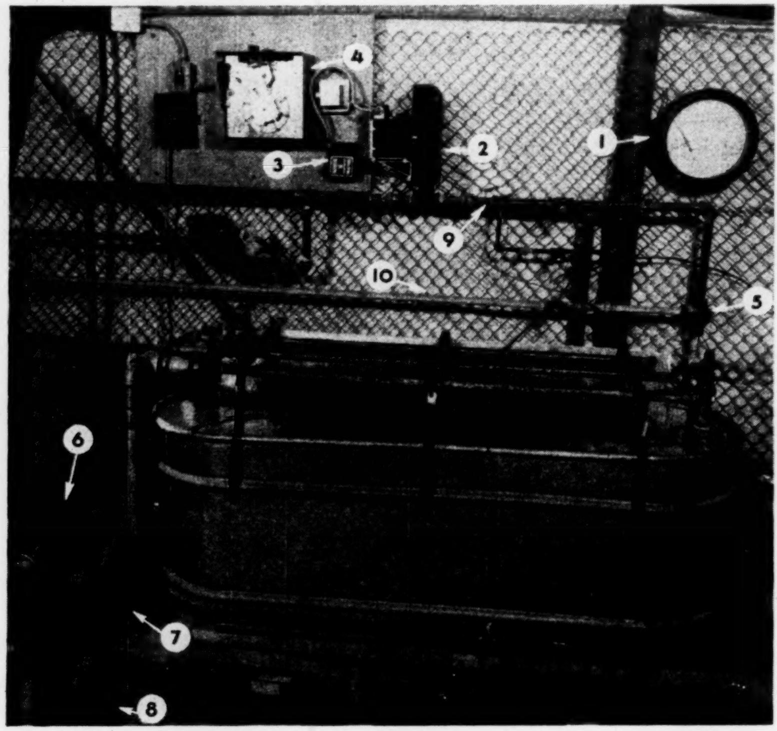

FIG. 1.—Exposure 10 Flow Tank Apparatus.

1—Temperature recorder. *2*—Motorized valve. *3*—Temperature controller. *4*—Clock with mercoid switches to operate motor valve. *5*—Mixing valve. *6*—Motor. *7*—Pump. *8*—Suction line. *9*—Steam line. *10*—Tap water line.

In the development of exposure 10, several modifications were tried in an attempt to keep the exposure period to a minimum and yet allow discrimination to be made between good and bad cement-aggregate combinations. One of the modifications, referred to as exposure

10-1, consisted of varying the spray-water temperature from 68 to 118 F. A significant difference between the results obtained from exposure 10 (spray-water temperature of 68 to 130 F) and the modified exposure 10-1 (spray-water temperature of 68 to 118 F) is pointed out later. Figure 3 shows the temperature difference between the water and center of beam through a complete cycle for exposures 10 and 10-1.

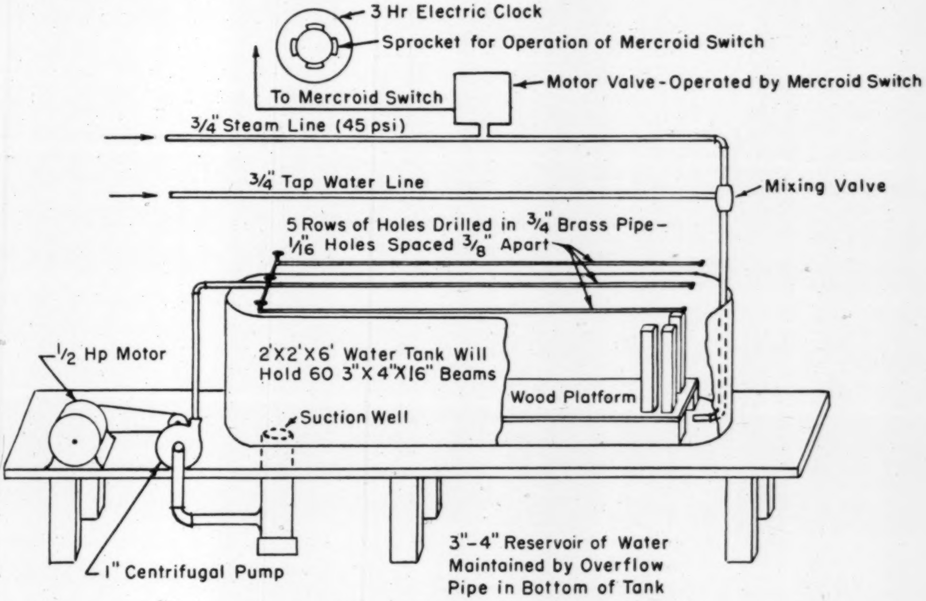
3 Hr Electric Clock
Sprocket for Operation of Mercroid Switch
To Mercroid Switch
Motor Valve-Operated by Mercroid Switch
3/4" Steam Line (45 psi)
3/4" Tap Water Line
Mixing Valve
5 Rows of Holes Drilled in 3/4" Brass Pipe-
1/16 Holes Spaced 3/8" Apart
1/2 Hp Motor
2'X2'X6' Water Tank Will
Hold 60 3"X4"X16" Beams
Wood Platform
Suction Well
1" Centrifugal Pump
3"-4" Reservoir of Water
Maintained by Overflow
Pipe in Bottom of Tank

FIG. 2.—Schematic Drawing of Exposure 10.

WETTING-AND-DRYING EXPOSURE—EXPOSURE 2

Exposure 2 is a wetting-and-drying cycle which consists of placing the specimens in a drying oven at 130 F for 8 hr, followed by immersion in water at 70 to 80 F for 16 hr. The cycle is repeated five days each week, the specimens remaining immersed over Saturdays and Sundays. A comparison of wetting-and-drying tests with a field survey made by White (2) showed that cement-aggregate combinations that expand as much as 0.07 per cent or more in 1 yr in the wetting-and-drying tests have a poor service record.

SPECIMENS AND CURING

The type of specimens and preliminary curing procedures were the same for exposures 2, 10, and 10-1. The specimens were 3 by 4 by 16-in. beams provided with gage points in each end. All beams were cured 24 hr in the molds in the moist closet, six days in the moist room, and then stored on racks in the air-conditioned laboratory at 74 F and 55 to 60 per cent relative humidity for 21 days. All specimens were then placed in water at 70 F for two days before the exposure tests were started at 30 days of age. In addition to the 30-day curing, several concretes were cured only 7 days in the moist room before being placed in exposure 10-1.

Concretes that were cured only 7 days

in the moist room developed longitudinal cracks on the 4-in. face of the specimen at early ages of the test. The 30-day curing partially eliminated the longitudinal cracking so that the cracks developed only occasionally. These cracks are evidently caused by thermal stresses; unless expansion accompanies this cracking, it should not be considered to be evidence of adverse reaction. Because there is only occasional cracking with 30-day curing, tests should not be started before this age has been attained.

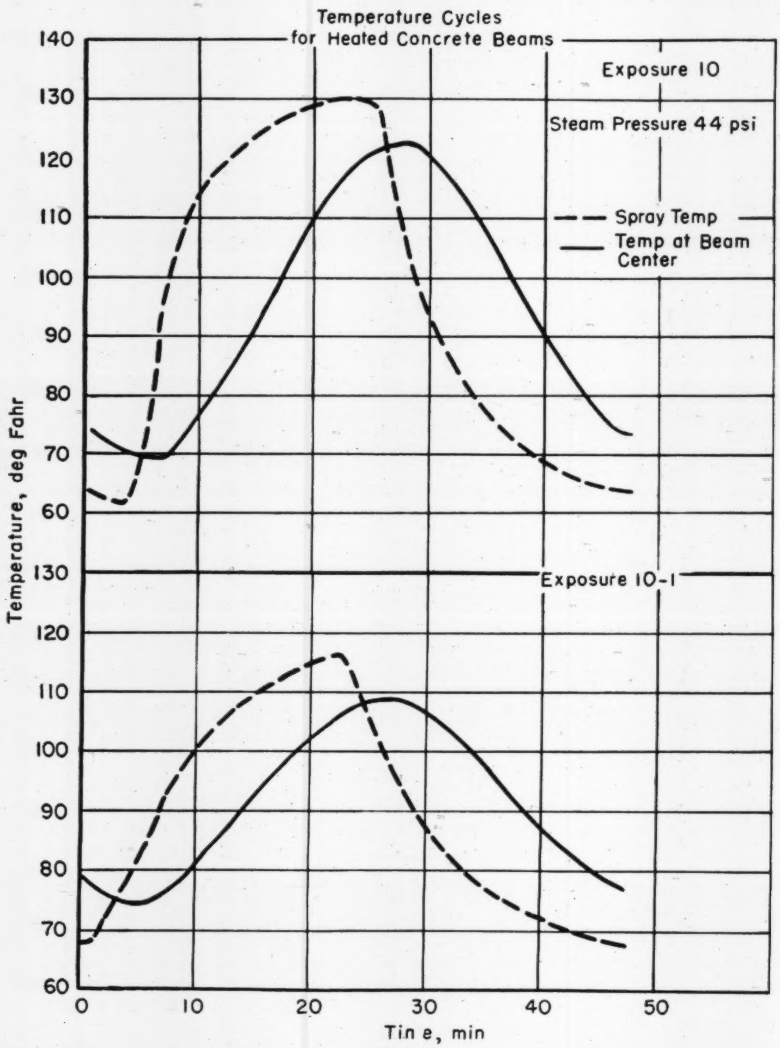

FIG. 3.—Relation of Spray Water Temperature and Beam Temperature for Exposures 10 and 10-1.

CONCRETES AND MATERIALS

A wide variety of cements, aggregates, and pozzolanic materials were used in various combinations to obtain some 69 concretes of various characteristics. The concretes were made with a variety of cements having a wide range in chemical analysis, particularly in alkali content as expressed by sodium equivalent (Table I).

The aggregates were obtained from various localities, and their field service records in concrete structures had been fairly well established:

Aggregate	Source	Field Service Record
Republican River sand gravel (S.G.)	Wakefield, Kans.	Poor
Beloit sand	Wisconsin,	Excellent
Eau Claire sand	Eau Claire, Wis.	Excellent
Kaw River S.G.	Manhattan, Kans.	Poor
Platte River S.G.	Nebraska	Poor
Blue River S.G.	Manhattan, Kans.	Good
Water slag[a]	Chicago, Ill.	Unknown

[a] A molten glass material cooled in water and collected from bottom of powdered coal-burning furnace.

In some instances, the aggregates listed above having a generally poor service record have demonstrated a good field performance when used with certain cements.

The concrete mixtures produced concretes with workability and economy normally recommended for the majority of structures. The essential mixing data are included on the figures showing the expansion of the test specimens.

CORRELATION OF EXPOSURE 2 WITH FIELD EXPOSURE

Considerable data are available for comparison of the wetting-and-drying test (exposure 2) to field exposure, from which it would appear that the method shows rather satisfactory correlation with field exposure. A comparison of the expansion of concretes subjected to 7.5 yr of outside weathering (3, 4) with exposure 2 is given in Fig. 4.

It is to be noted that there are marked differences in performance of the concretes made with the two sand gravels. With the Kaw River aggregate there was a marked difference in the extent of the deterioration of concretes made with the different cements. With this aggregate, which has a poor service record, 11 cements developed an expansion of 0.07 per cent or more in the wetting-and-drying test, and 10 of the cements developed more than 0.1 per cent expansion in outdoor exposure. On the other hand, with the Blue River aggregate, which has a good service record, only one of the 24 cements developed an expansion of

TABLE I.—CHEMICAL ANALYSIS OF CEMENTS, PER CENT.

Cement	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Loss on Ignition	K_2O	Na_2O	Na_2O Equivalent of Total Alkali
A	20.7	6.00	3.45	63.18	2.84	2.07	1.05	0.45	0.27	0.57
D	20.77	5.90	2.82	62.23	2.77	2.30	1.07	0.59	0.28	0.67
H	22.24	5.86	3.01	64.46	0.51	2.08	1.19	0.52	0.32	0.66
N	20.90	6.55	2.55	63.63	1.96	1.89	1.55	0.21	0.28	0.42
R	21.24	4.72	2.48	63.91	4.40	1.87	1.00	0.73	0.16	0.64
U	21.00	5.78	2.49	63.30	3.52	2.03	1.22	0.74	0.16	0.65
Y	20.73	2.22	6.68	63.85	2.31	0.73	1.88	1.40	0.20	1.12

more than 0.07 per cent in the wetting-and-drying cycle, and this same cement was the only one that developed an expansion of more than 0.1 per cent after 7.5 yr of outdoor exposure.

DISCUSSION OF CONTINUOUS SPRAY EXPOSURE

Figures 5 through 10 show a comparison of the expansion from wetting and drying (exposure 2) with the expansion from a continuous spray of water (exposure 10). Figure 5 shows that very little expansion occurs in exposure 10-1 (spray temperature 68 to 118 F) even though the concretes were subjected to 4000 cycles (in approximately 125 days). On the other hand, 6 of the 12 concretes showed 0.1 per cent expansion after only 2000 cycles in exposure 10 (spray temperature 68 to 130 F). Furthermore, the correlation between the expansion after 360 days of wetting and drying in exposure 2 and expansion after 2000 cycles in exposure 10 is exceptionally good, particularly for the discrimination between good and bad cement-aggregate combinations. Just why the lower temperature used in exposure 10-1 does not accelerate the rate of deterioration is not quite understood. This fact seems to indicate that at least part of the mechanism associated with cement-aggregate reaction is a physical as well as a chemical phenomenon.

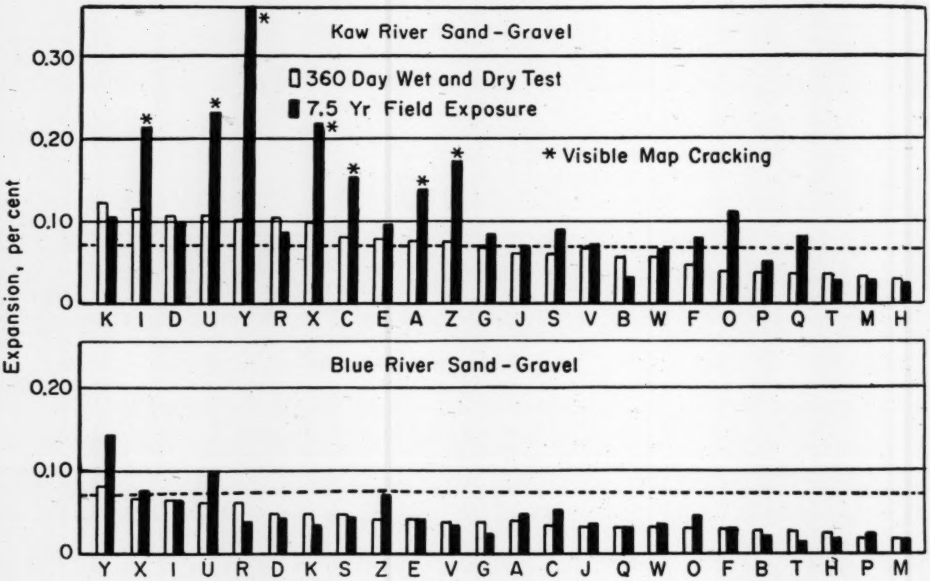

FIG. 4.—Comparison of Expansion from Wetting-and-Drying Tests with Expansion from Field Exposure. Cements arranged in descending order of expansion in exposure 2.

A review of Figs. 5 through 10 will show a reasonably good correlation between the wetting-and-drying test and the continuous spray of water. The only discrepancy between the two types of exposure is that several of the concretes developed little expansion in exposure 2 but developed considerable expansion in exposure 10. *In other words, a concrete that shows a satisfactory performance in exposure 10 could be expected to do likewise in exposure 2.*

It is difficult to determine the merit

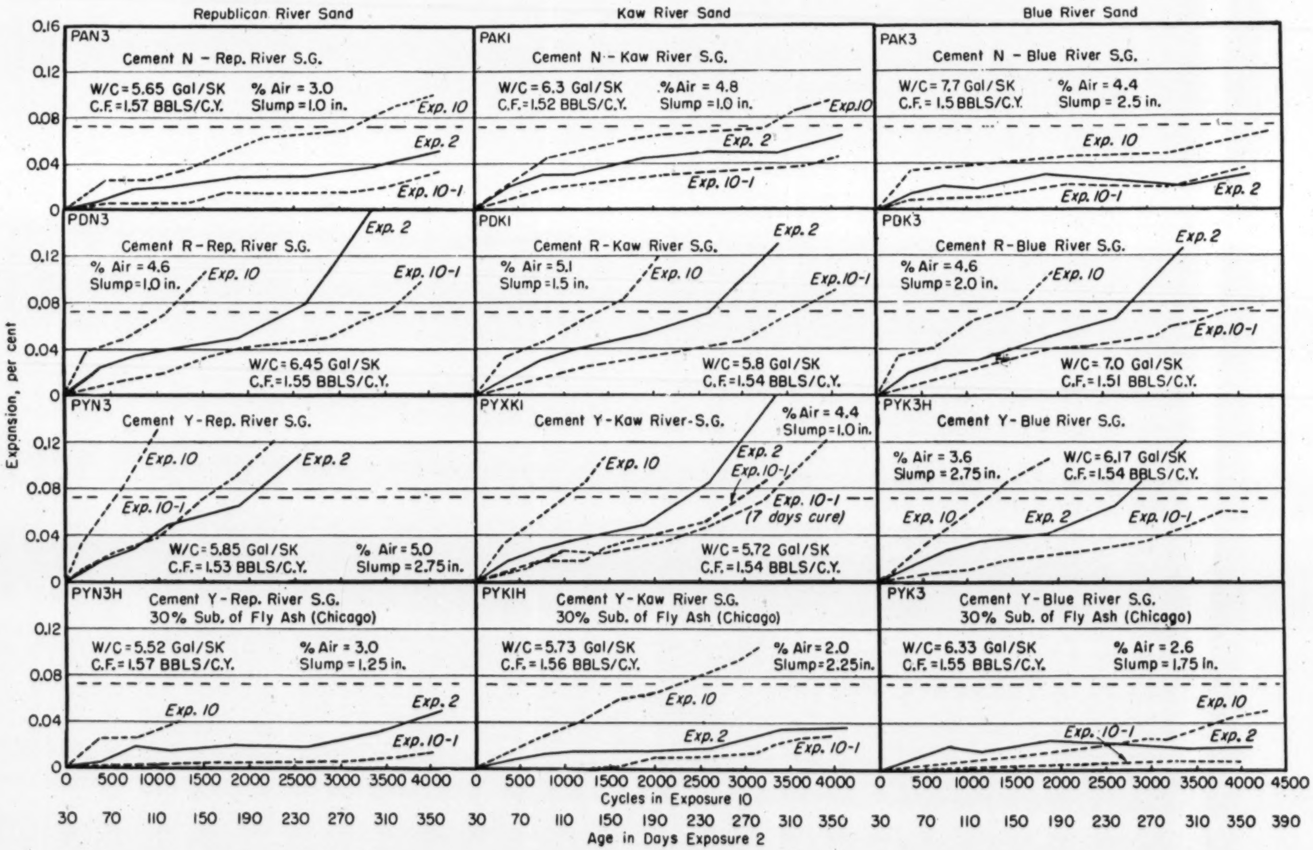

FIG. 5.—Comparison of Expansion from Wetting and Drying (Exposure 2) With Expansion From a Continuous Spray of Water (Exposure 10).

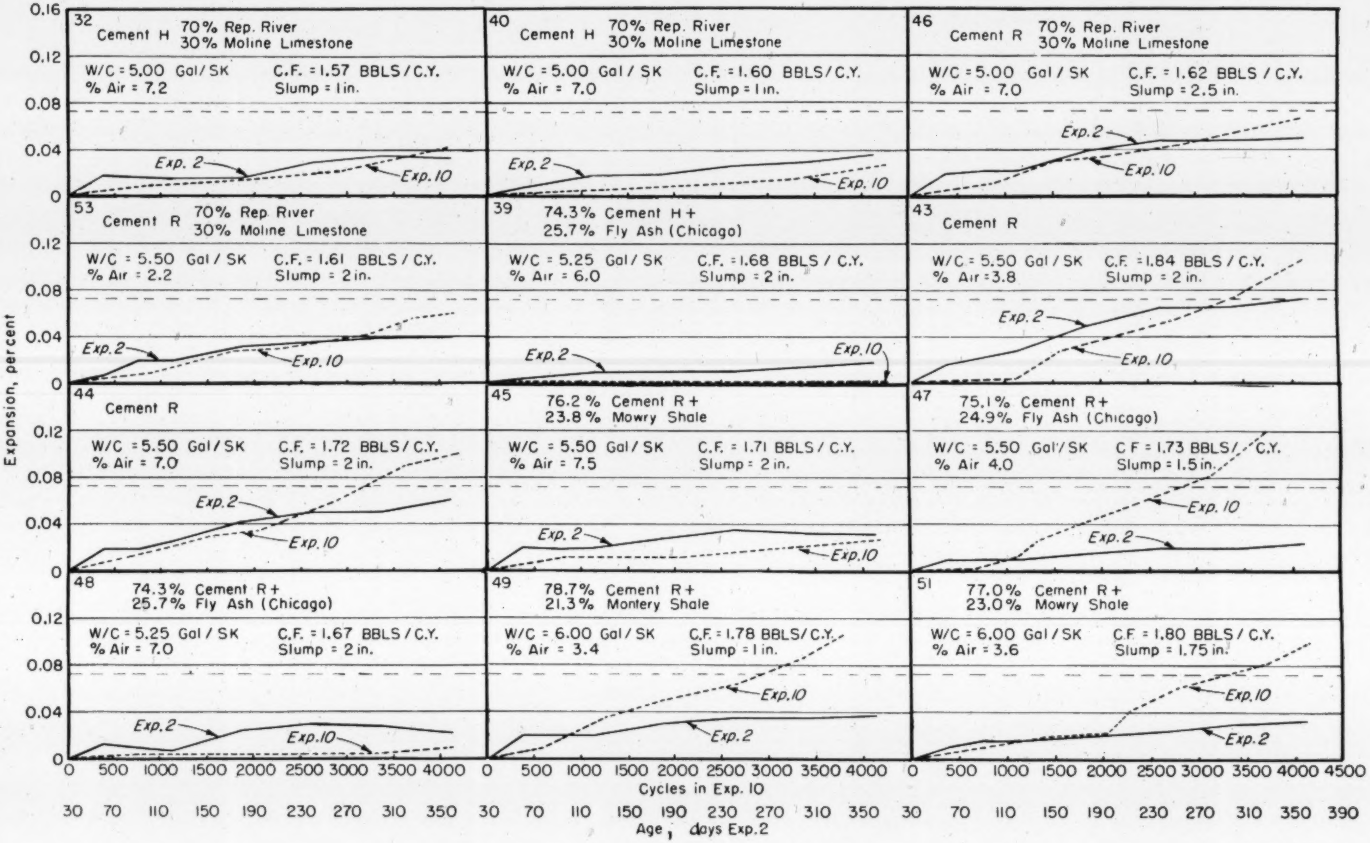

FIG. 6.—Comparison of Expansion From Wetting and Drying (Exposure 2) With Expansion From a Continuous Spray of Water (Exposure 10). Republican River (K6), Wakefield, Kans.

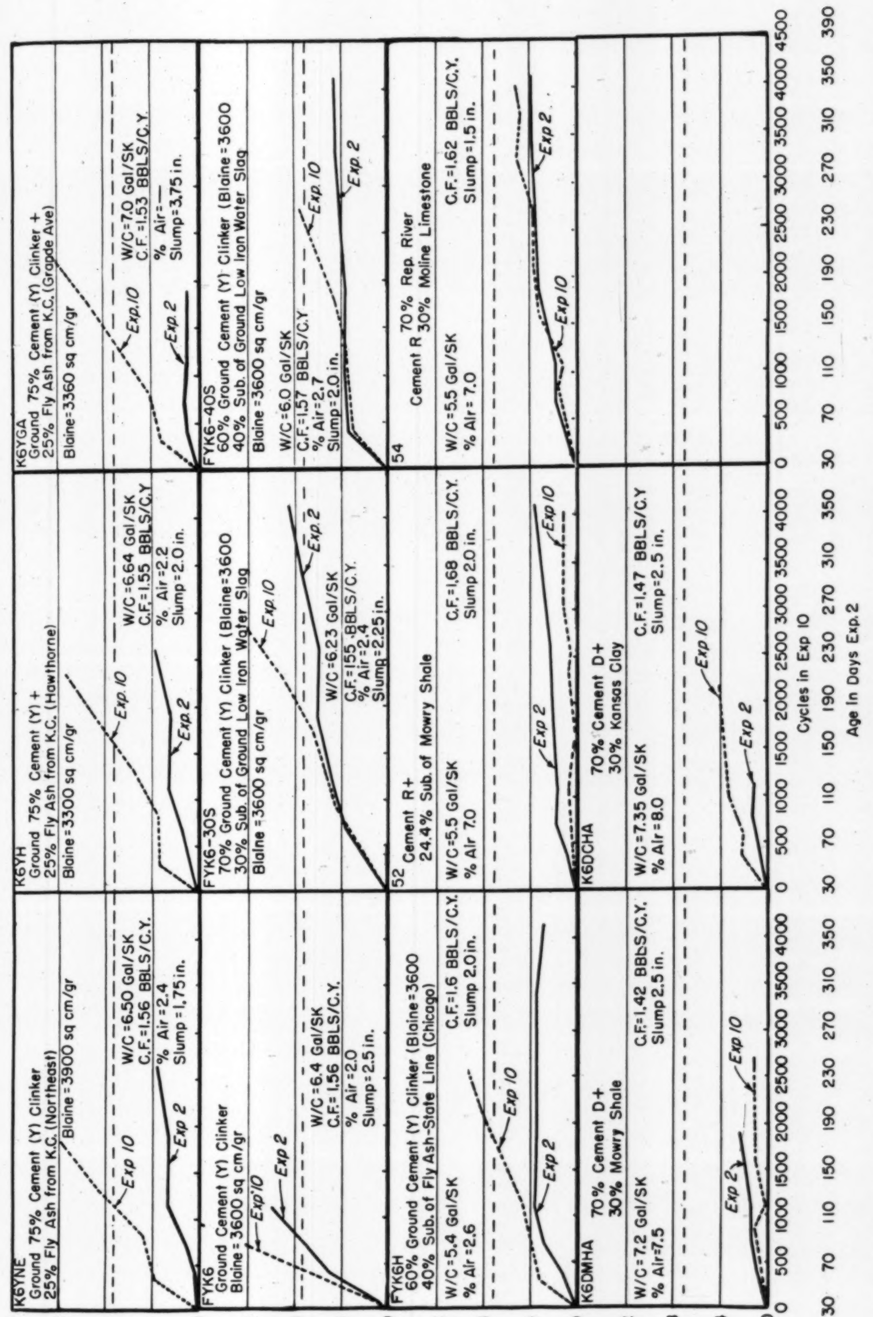

Fig. 7.—Comparison of Expansion From Wetting and Drying (Exposure 2) With Expansion From a Continuous Spray of Water (Exposure 10). Republican River S. G. (Wakefield).

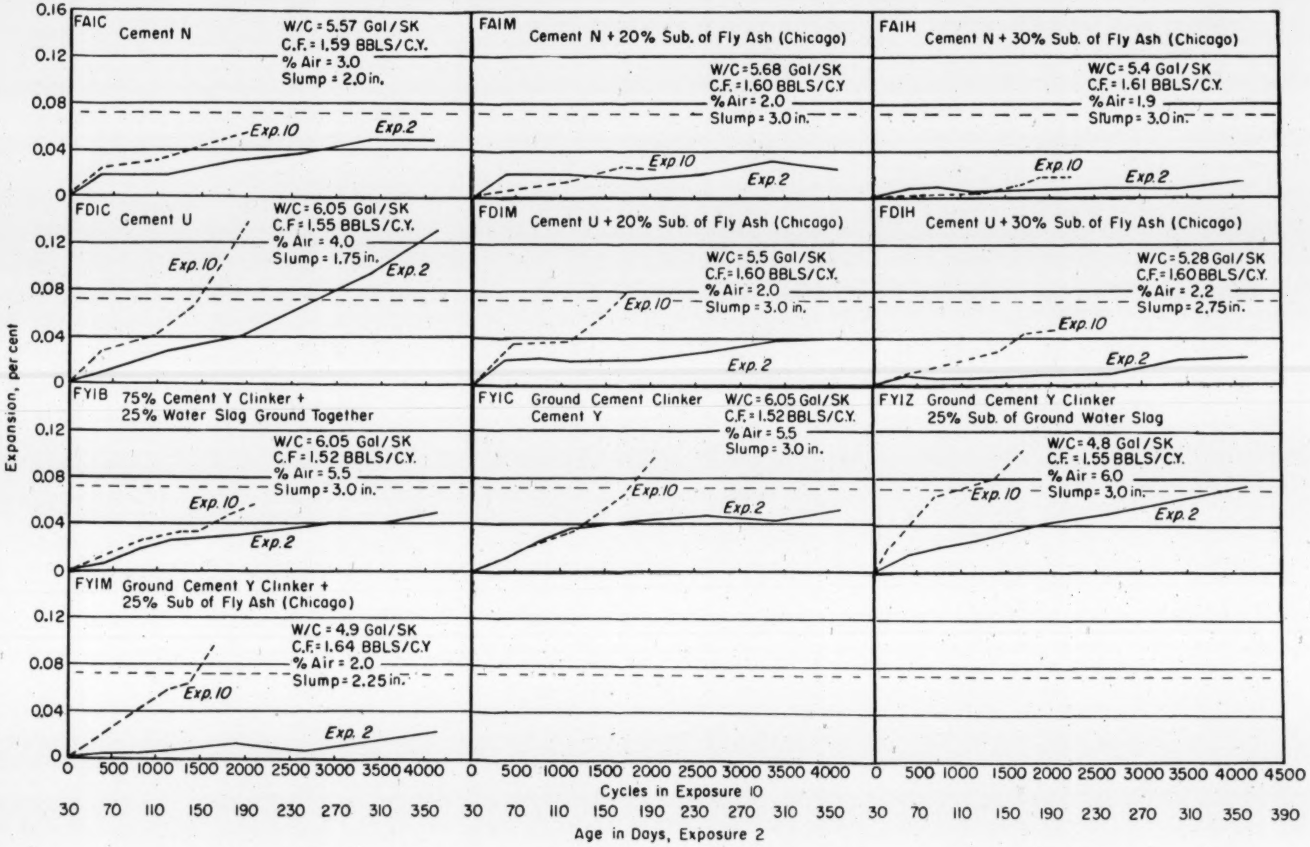

FIG. 8—Comparison of Expansion From Wetting and Drying (Exposure 2) With Expansion From a Continuous Spray of Water (Exposure 10). Platte River sand.

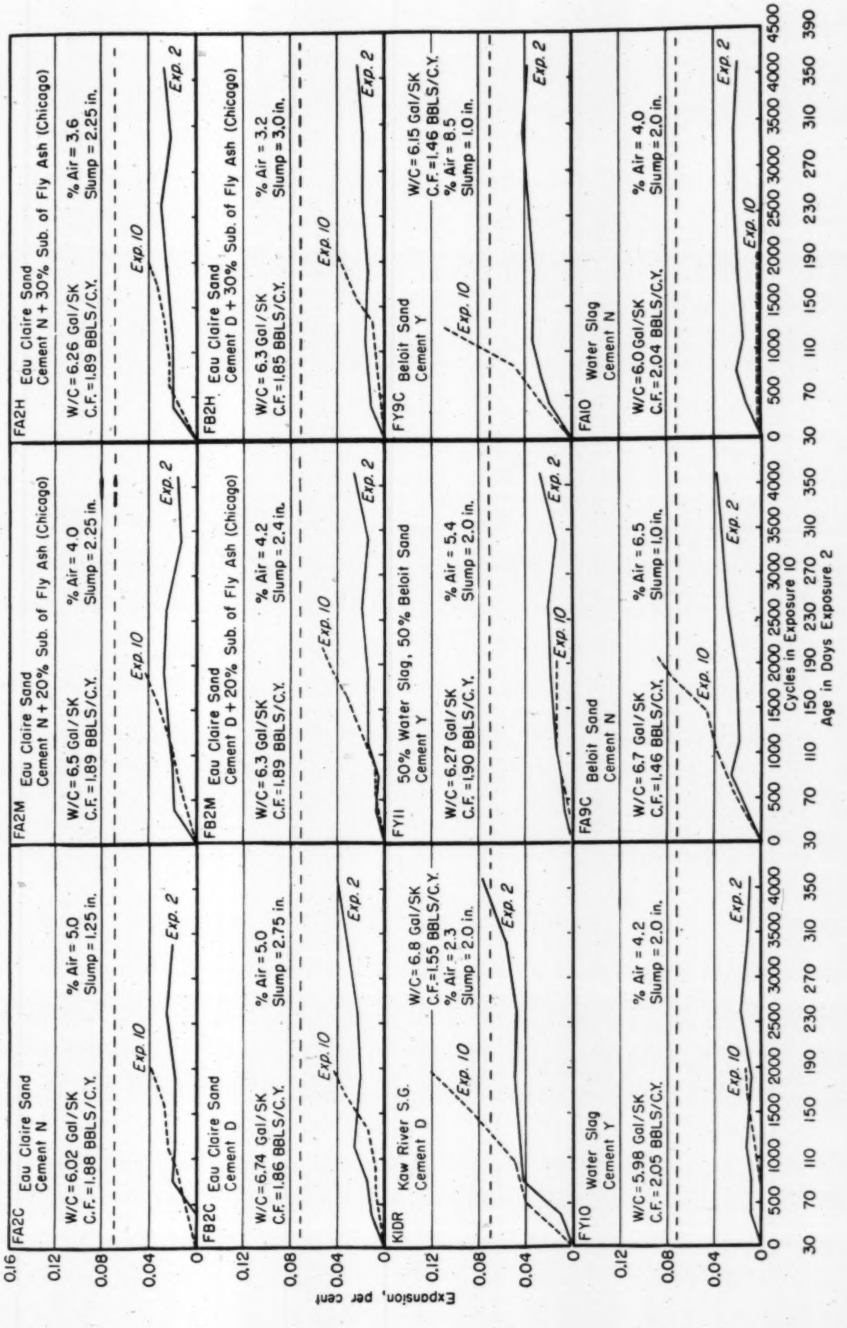

FIG. 9.—Comparison of Expansion From Wetting and Drying (Exposure 2) With Expansion From a Continuous Spray of Water (Exposure 10). Miscellaneous cement and aggregate combinations.

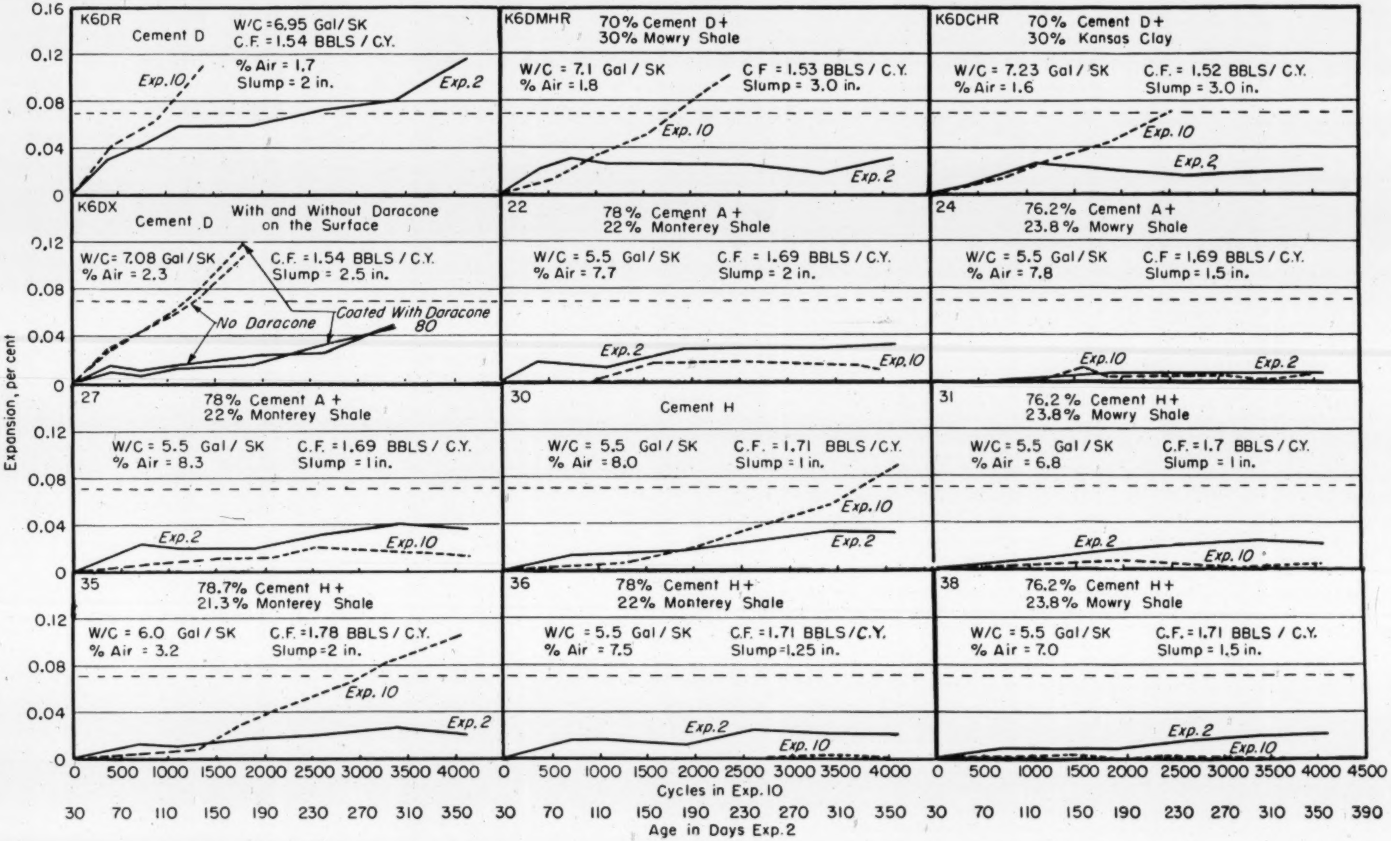

FIG. 10.—Comparison of Expansion From Wetting and Drying (Exposure 2) With Expansion From a Continuous Spray of Water (Exposure 10). Republican River (K6), Wakefield, Kans.

of an accelerated test that is to simulate field conditions because of the complexity and inherent nature of concrete. To some extent, the correlation of exposure 10 has been made indirectly with the field service record through exposure 2 (**3**, **4**). Almost without exception, however, the service records of concrete structures throughout Kansas and Nebraska show an excellent correlation with the expansion after one year in exposure 2. In view of this, it would not seem unreasonable to expect a satisfactory service record from a concrete that has shown an expansion of 0.07 per cent or less during 2000 cycles in exposure 10. In instances of borderline cases further tests and studies of the concrete are recommended.

The authors believe that exposure 10 is a suitable rapid method of test for studying cement-aggregate reactions or incompatibility of all the constituents of concrete. The apparatus is simple, inexpensive, and requires a minimum of handling of the specimens during the testing cycles.

CONCLUSIONS

The significant facts about exposure 10 that make it of unusual value as a means of studying cement-aggregate reaction are as follows:

1. A period of 90 days from the time of casting specimens is sufficient to discriminate between concretes with undesirable expansion and those with little or no expansion. The 90-day period includes a 30-day curing period followed by approximately 60 days exposure to the test.

2. This test makes it possible to study the effects of other constituents of concrete—the cement, the fine aggregate, the coarse aggregate, and any additions or treatments that might be introduced.

3. The equipment is automatic and requires a minimum of handling of the specimens during the exposure period.

4. The results from exposure 10 parallel rather closely field observations and the laboratory wetting-and-drying tests of exposure 2. As an example, studies at Kansas State College (**4**) and the result of field observations show that certain coarse aggregates such as a limestone definitely inhibit the deterioration of concrete from cement-aggregate reaction. The results from exposure 10, as shown in Figs. 6 and 7, exhibit practically no expansion for concretes containing Moline limestone.

5. Concretes that show a satisfactory performance in exposure 10 could be expected to do the same in the wetting-and-drying tests of exposure 2 and in the field.

REFERENCES

(1) C. H. Scholer, "A Wetting and Drying Test for Predicting Cement-Aggregate Reaction," *Proceedings*, Am. Soc. Testing Mats., Vol. 49, p. 942 (1949).

(2) L. V. White, "Inspection of Concrete Structures, Republican and Blue River Watersheds," Engineering Experiment Station, Kansas State College, Manhattan, Kans., 122 pp. (1941). Unpublished report.

(3) C. H. Scholer and G. M. Smith, "A Study of Certain Cement-Aggregate Reactions in Outside Weathering and Laboratory Wetting-and-Drying Tests," a cooperative report of the Engineering Experiment Station, Kansas State College, and the Portland Cement Assn., 23 pp. (1951).

(4) C. H. Scholer, and W. E. Gibson, "Effect of Various Coarse Aggregates Upon the Cement-Aggregate Reaction," *Journal*, Am. Concrete Inst., Vol. 19, No. 10, June, 1948.

STATISTICAL RELATION BETWEEN CYLINDER, MODIFIED CUBE, AND BEAM STRENGTH OF PLAIN CONCRETE*

By Clyde E. Kesler[1]

Synopsis

The relationship between the cylinder, modified cube, and beam strength of plain concrete is determined statistically for concrete having varying strengths and made from different mixes. The aggregates used were the same for all specimens. The results presented are based on over 1400 individual static tests involving concrete of different strengths and ages.

Beams having 6 by 6-in. cross-section were tested on two different span lengths, 60 and 18 in. Modified cube tests were conducted on the broken pieces obtained from these beam tests. Cylinders tested were standard 6 by 12-in. size.

The information obtained from these tests has been presented in five graphs which have been fitted with "least squares" curves. For each curve the coefficient of correlation and the standard error of estimate is given.

It is often desirable to know the relationship between modulus of rupture and the compressive strength of concrete. This relationship is often involved in various specifications and consequently should be well established. In connection with various investigations at the University of Illinois, a considerable amount of data has been accumulated on flexure tests and compression tests. The flexure tests were made on spans of 60 and 18 in. The compression tests were made on both the modified cube and the standard cylinder. The specimens for the modified cube test were obtained from the flexure tests that were made on the 18-in. span. The information obtained from these tests has been analyzed statistically and the results are presented herein.

Materials

Both the fine and coarse aggregates are from the Wabash River near Covington, Ind. These aggregates are part of a glacial outwash probably from the Wisconsin glaciation. The sand has an average fineness modulus of 3.0. The coarse aggregate was well graded and had a maximum size of 1 in. The bulk specific gravities were 2.66 and 2.70 for sand and gravel, respectively. The absorption of the aggregates was about 1 per cent by weight of the surface dry aggregate. Both of these aggregates passed the usual specification tests. The cement used was a type I portland cement. This cement was purchased in paper bags from time to time, and several brands were used.

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13–18, 1954.

[1] Associate Professor of Theoretical and Applied Mechanics, University of Illinois, Urbana, Ill.

The mixtures used were such that good, workable concretes were obtained. The compressive strength of the cylinders varied from about 1500 to nearly 7000 psi. The slump varied from 1 to 7 in. The concrete was mixed in a Lancaster pan-type mixer of about 2-cu ft capacity.

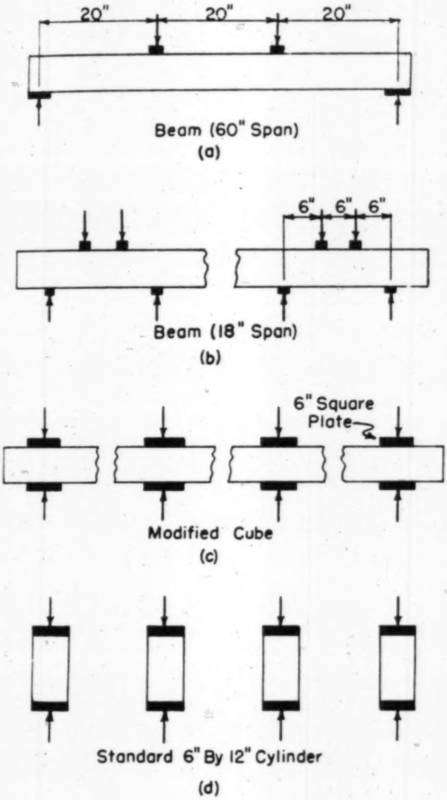

FIG. 1.—Types of Test Specimens.

From each batch of concrete one beam 6 by 6 by 64 in. and four standard 12-in. cylinders were cast. The concrete was cured in a moist room, having a temperature of about 74 F and a relative humidity of 100 per cent, for seven days and then cured in the normal laboratory atmosphere until tested. This is not the 28-day moist curing recommended by ASTM for standard tests.

METHODS OF TESTING

The 60-in. beams were loaded as shown in Fig. 1(*a*) and tested to failure under either static or repeated load. A system of rollers and balls was used in the loading equipment to eliminate torsion on the specimen. The "halves" were then subjected to flexure tests, Fig. 1(*b*), using an 18-in. span and third-point loading as outlined in the ASTM Standard Method of Test for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading) (C 78 – 49),[2] except that the half beams were not turned on their sides previous to being tested in flexure. While the specimen weight was included in the computation for the modulus of rupture for beams tested on the 60-in. span, it was not included for the beams tested on the 18-in. span. Owing to the shortness of the 18-in. span and also to the fact that there was overhang of the specimen, any stress due to the weight of the specimen would be insignificant.

Upon completion of the flexure tests on the 18-in. span, four pieces of each original beam were available. These were tested as modified cubes, Fig. 1(*c*), according to ASTM Standard Method of Test for Compressive Strength of Concrete Using Portion of Beams Broken in Flexure (C 116 – 49).[3] The cylinders were tested, Fig. 1(*d*), in general accordance with the ASTM Standard Method of Test for Compressive Strength of Molded Concrete Cylinders (C 89 – 49).[4]

The modified cube specimens were capped with Hydrocal gypsum cement at least six hours before testing; the cylinders were cast on machined cast iron plates and were capped with neat cement three or four hours after casting. The ages of specimens at the time of testing varied from about 3 to about 9 months.

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[2] 1952 Book of ASTM Standards, Part 3, p. 1051.

[3] *Ibid*, p. 1038.

[4] *Ibid*, p. 1040.

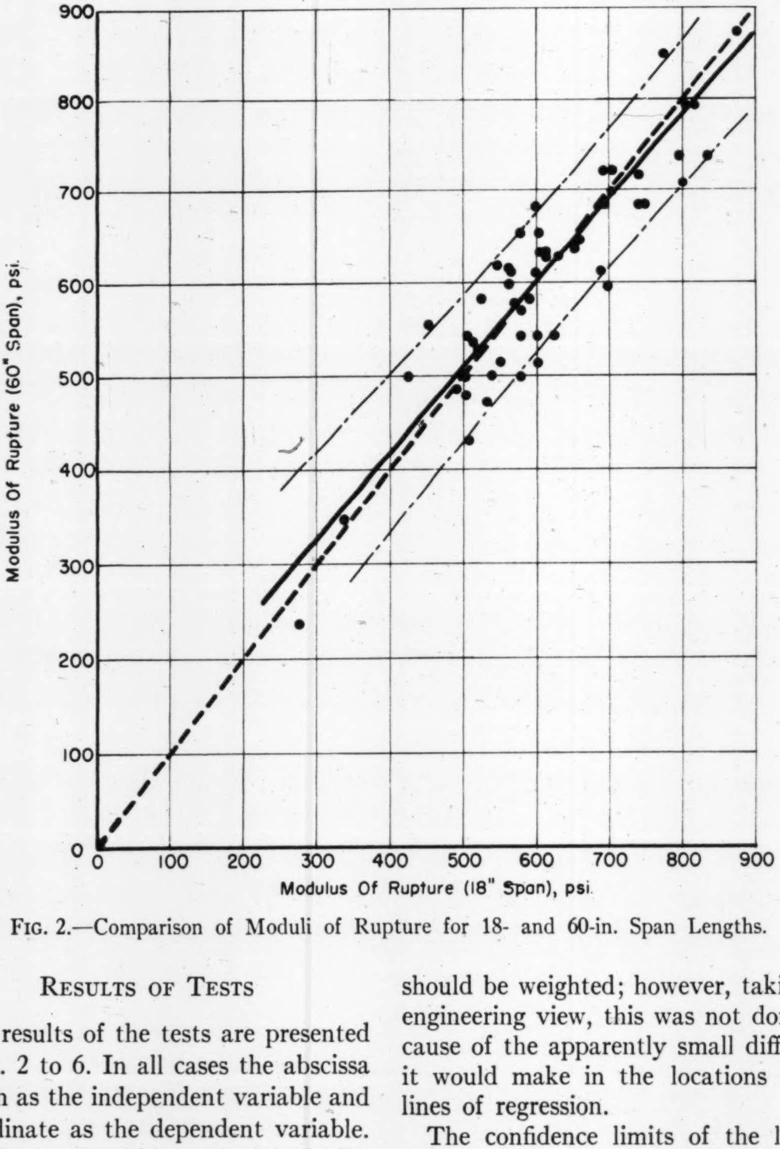

FIG. 2.—Comparison of Moduli of Rupture for 18- and 60-in. Span Lengths.

RESULTS OF TESTS

The results of the tests are presented in Figs. 2 to 6. In all cases the abscissa is taken as the independent variable and the ordinate as the dependent variable. These figures should be approached with the thought that if the true value of the independent variable is known then the line of regression will give a reasonably good estimate of the dependent variable. As will be noted, there are different numbers of observations for the different parameters. To be strictly correct these should be weighted; however, taking an engineering view, this was not done because of the apparently small difference it would make in the locations of the lines of regression.

The confidence limits of the line of regression for the quantity being predicted are shown at the 90 per cent level. These limits are shown as dash-dot lines on the figure. The odds are about 9 to 1 against any values falling outside these limits. The coefficient of correlation when given applies to the sample correlation and is only an estimate of the true correlation of the universe.

A comparison of the moduli of rupture for beams tested on spans of 60 and 18 in. was made in Fig. 2. All 56 points in this figure were obtained from static load tests. The solid line was determined statistically by the "least squares" method, while the dashed line represents equality of the moduli of rupture for the two span lengths. The coefficient of correlation for the line of regression of the modulus of rupture of beams tested on a span of 60 in. to that of beams tested on a span of 18 in. is 0.86 and for the dashed line is 0.85. The standard error of estimate of the modulus of rupture on a 60-in. span is 45 psi for the line of regression and 47 psi for the dashed line. This indicates that the modulus of rupture obtained from a test on a span of 18 in. may, with little error, be considered the same as that obtained if the specimen were tested on a span of 60 in. Even though the "halves" used in the tests with the 18-in. span had previously been subjected to bending in the tests with the 60-in. span, it is believed their ultimate flexural strength was unaffected.[5]

The relationship obtained between the cylinder strength and the modified cube strength is shown in Fig. 3. The speci-

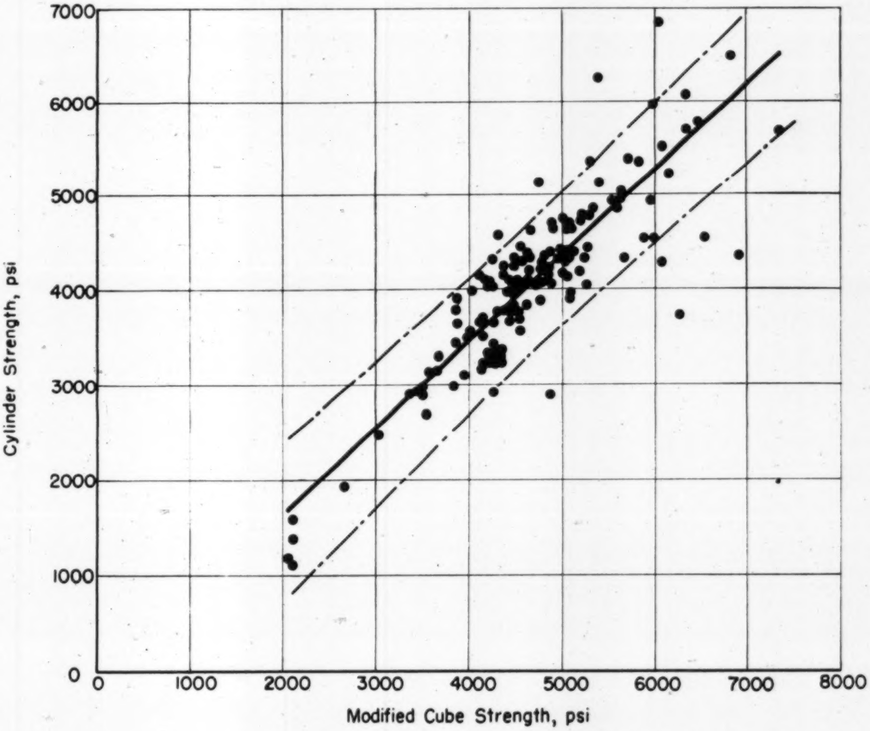

FIG. 3.—Line of Regression of Cylinder Strength on Modified Cube Strength.

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[5] C. E. Kesler, "Effect of Speed of Testing on Flexural Fatigue Strength of Plain Concrete," *Proceedings*, Highway Research Board, Vol. 32, p. 251 (1953).

mens used for the modified cube test were from beams that had been subjected to a static flexure test first on a 60-in. span and also on an 18-in. span, or from beams that had been tested to failure under repeated loads on a 60-in. span and then tested statically on an 18-in. span. There are 147 points on this graph, each representing the average of four modified cube specimens and three or four cylinders. The line shown on the graph is the line of regression of the cylinder strength on the modified cube strength. The coefficient of correlation for the line of regression is 0.85, and the standard error of estimate for the cylinder strength is 420 psi. These tests indicate that the modified cube specimen gives a compressive strength significantly higher, about 20 per cent for concretes of average strength, than the standard cylinder for the same material. This is in contrast with a previous statement by Koenitzer[6] that the modified cube tests

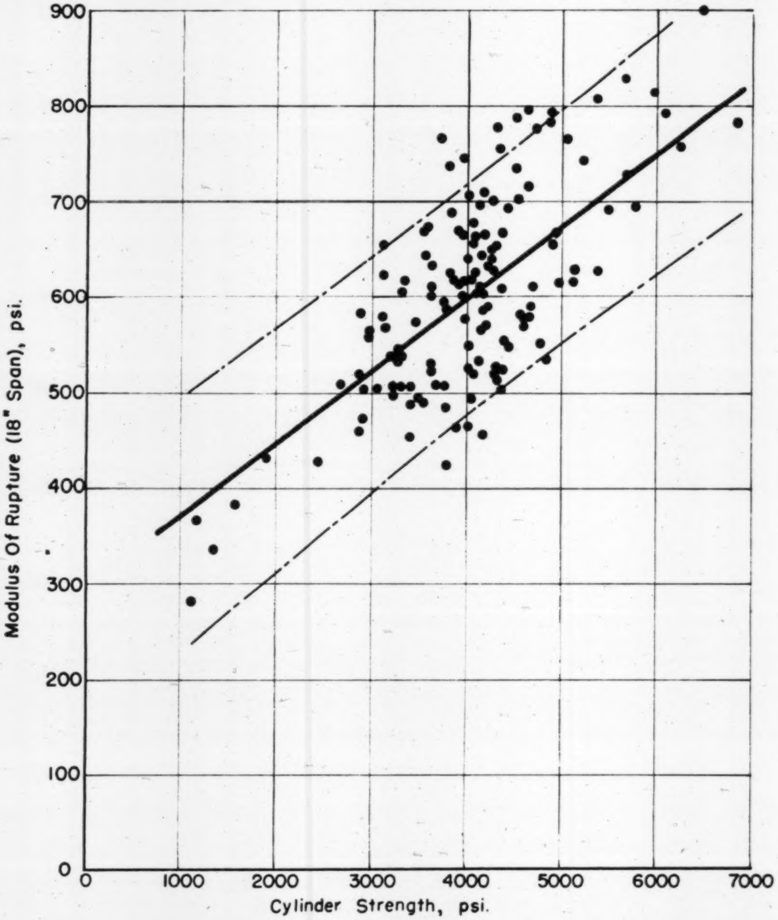

FIG. 4.—Line of Regression of Modulus of Rupture on Cylinder Strength.

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[6] L. H. Koenitzer, "Proposed Method of Making Compression Tests on Portions of Concrete Beams from Flexure Tests," *Proceedings*, Am. Soc. Testing Mats., Vol. 34, Part II, p. 406 (1934).

give results that are close to those obtained in tests of standard cylinders and that no correction factor need be applied.

Clemmer[7] and others[8] have stated that the results of modified cube tests are more consistent than those of cylinder tests. In order to check this statement, all the sets of tests having four modified cube specimens and four cylinder specimens made from one mix proportion were studied statistically. The average cylinder strength of this particular mix was 3500 psi. Twenty sets, 80 specimens each of modified cubes and cylinders, were available for this study. Each set was from a different batch of concrete. It was assumed the tests would have a normal distribution and the variance[9] for the modified cube tests was found to be 63,500 and for the cylinder tests, 55,800. A check made at the 10 per cent level indicated that this difference in variance was not significant. It is concluded, therefore, that one test is as consistent as the other.

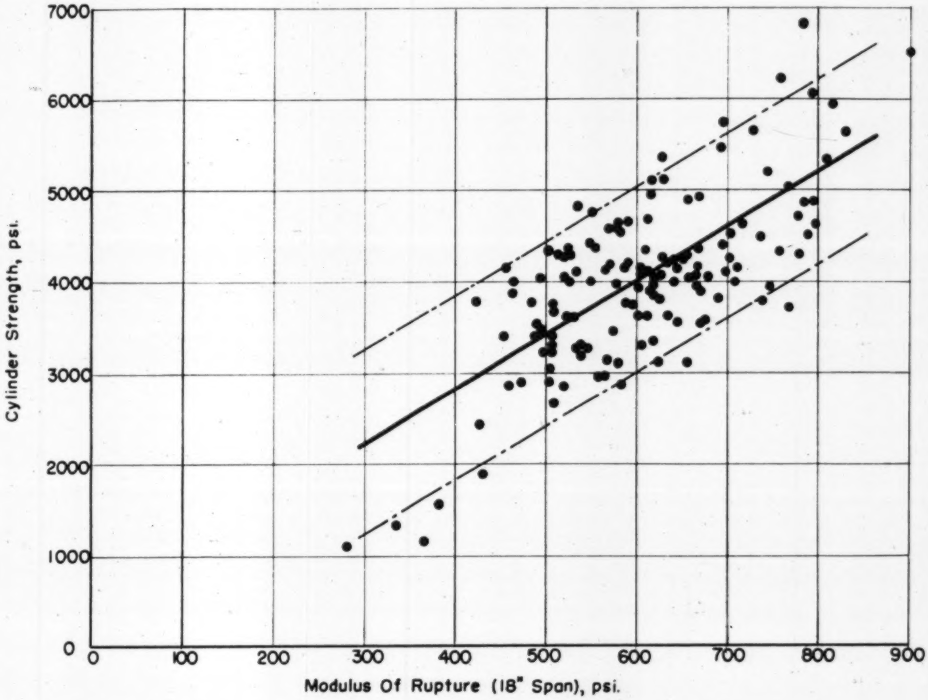

FIG. 5.—Line of Regression of Cylinder Strength on Modulus of Rupture.

The relation between the cylinder strength and the modulus of rupture for beams tested on an 18-in. span is shown in Fig. 4. There are 143 points on this graph. Each point represents the results of two flexure tests and three or four compression tests. This information was plotted three different ways, one being to an arithmetic scale as shown on Fig. 4

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[7] H. F. Clemmer, "Comparison of Transverse and Compressive Tests of Concrete," *Public Works*, Vol. 57, p. 204 (1946).

[8] "Factory Produces Prestressed Buildings," *Engineering News-Record*, March 19, 1953, p. 31.

[9] W. J. Dixon, F. J. Massey, Jr., "Introduction to Statistical Analysis," McGraw-Hill Book Co., Inc., New York, N. Y., p. 91 (1951).

and others to semilog and log-log scales. Different curves were fitted to the points plotted in these various ways, and it was concluded that a straight line on the arithmetic plot provided the best representation. For the line of regression shown, modulus of rupture on the cylinder strength, the coefficient of correlation is 0.70 and the standard error of estimate of the modulus of rupture is 75 psi. This graph shows that the mean value of the modulus of rupture varies from about 22 per cent of the compressive strength for the low-strength concrete to 12 per cent for the high-strength concrete.

In Fig. 5 is shown the line of regression of the cylinder strength on the modulus of rupture. The information used in this figure is the same as that used in Fig. 4, the variables being interchanged. The standard error of estimate of the cylinder strength is 630 psi. Figure 5 shows that the mean value of the compressive strength varies from about 7.5 times the modulus of rupture for low-strength to 6.5 times for the high-strength concrete.

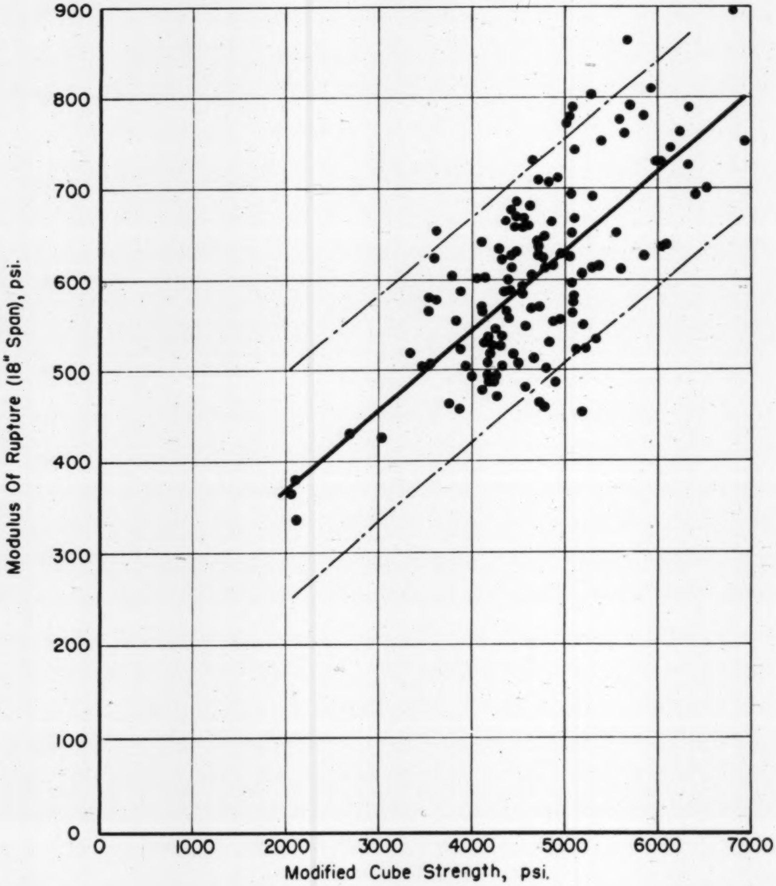

FIG. 6.—Line of Regression of Modulus of Rupture on Modified Cube Strength.

The relationship between the modulus of rupture and the modified cube strength is shown in Fig. 6. Each of 155 points shown here represents two flexure tests and four compression tests. For the line of regression shown, modulus of rupture on the modified cube strength, the coefficient of correlation is 0.74 and the standard error of estimate of the modulus of rupture is 75 psi. The coefficient of correlation for the relationship between the modified cube strength and the modulus of rupture is slightly better than for the relationship between the cylinder compressive strength and the modulus of rupture. This can probably be accounted for by the fact that the modified cube tests were made on portions of the same specimens that were used to obtain the modulus of rupture. It may also be seen from Fig. 6 that the mean value of the modulus of rupture varies from slightly less than 18 per cent of the modified cube strength for the low-strength concrete to about 12 per cent for the high-strength concrete.

CONCLUSIONS

From the information presented, for specimens cured and tested as described, the following conclusions may be drawn:

1. The modulus of rupture obtained from tests on a beam having a span of 18 in. and loaded at the third points does not vary significantly from that obtained from tests on a beam having a span of 60 in. and loaded at the third points.
2. The mean value of the modulus of rupture varies from about 22 per cent of the mean value of the cylinder compressive strength for the low-strength concrete to about 12 per cent for the high-strength concrete. The standard error of estimate of the modulus of rupture is 75 psi.
3. The mean value of the cylinder strength varies from 7.5 times the modulus of rupture for the low-strength to 6.5 times for the high-strength concrete. The standard error of estimate of the cylinder strength is 630 psi.
4. The mean value of the modulus of rupture varies from about 18 per cent of the mean value of the modified cube strength for the low-strength concrete to about 12 per cent for the high-strength concrete. The standard error of estimate of the modulus of rupture is 75 psi.
5. The standard concrete cylinder gives a compressive strength having a mean value about 80 per cent of the mean value of the modified cube strength for low-strength concrete but about the same or only slightly lower strength for high-strength concrete. The standard error of estimate of the cylinder strength is 420 psi.
6. There is no significant difference between the consistency of the values from the cylinder and modified cube tests.

It is believed that the information presented will apply in general to any concrete of good design manufactured with sound natural aggregates. The relationships between the modulus of rupture and compressive strength will probably be different for concrete made with crushed aggregate. It is expected that certain admixtures will affect these relationships somewhat and that the use of lightweight aggregates may give entirely different values for the relationships presented.

It is not intended that these curves be used to obtain quantitative values, but they are put forth only to indicate what might reasonably be expected. However, the larger the number of observations the more accurate the predictions.

Acknowledgment:

This work was carried out in Talbot Laboratory as a project of the Engineer-

ing Experiment Station in the Department of Theoretical and Applied Mechanics at the University of Illinois. The author wishes to thank Mr. Tetsuichi Mitsuda, a former graduate student in the Department of Theoretical and Applied Mechanics, who carried out many of the statistical computations.

DISCUSSION

MR. C. H. SCHOLER.[1]—I wish to comment on the relationship between compressive strengths and flexural strengths of concretes as indicated in Mr. Kesler's paper. Our experience would indicate that the data he has secured are substantially in agreement with our results with one highly significant exception. When concrete has been subjected to deteriorating influences such as freezing and thawing or cement-aggregate reaction, these relationships break down. In many instances, in fact in hundreds of cases, virtually no loss in compressive strength may occur due to the deteriorating influences, but losses as high as 60 per cent in flexural strength may be shown.

It is my judgment that in any test where deteriorating influences may have developed, the compressive strength may be a very inadequate measure of the damage done to the concrete. Any assumption of a relationship between flexural and compressive strength would be unjustified in such instances.

MR. T. F. WILLIS[2] (*by letter*).—A few words concerning Mr. Kesler's statement about the "confidence limits" of his regression lines seem called for. Regarding these limits, Mr. Kesler says "the odds are about nine to one against any values falling outside these limits." As worded the statement is erroneous. Interpreted literally, and expressed in terms of probability instead of odds, the statment indicates the probability to be 0.9 that not even one measured value of the dependent variable (regardless of the number of different values considered) will fall outside the confidence limits. Actually 0.9 is the probability, applicable individually to each measured value of the dependent variable, that such value will not fall outside these limits (or that it will fall inside these limits). With this in mind, if we consider 56 values, such as are included in Fig. 2, the probability that no value will fall outside the confidence limits is 0.9^{56} or 0.003−; hence "the odds against *any* value falling outside" are only about 1 to 332. This is vastly different from nine to one and indicates practical certainty that one or more values will fall outside.

The idea the author probably intended to convey was that, for any one specific concrete belonging to the population sampled (which concrete has a value of the independent variable within the range covered by his experimental sample), if one predicted that the measured value of the dependent variable would fall within the confidence limits, the odds are nine to one that he would be right.

It should perhaps also be pointed out that under a rigorous interpretation of the mathematics involved, one cannot use an estimated regression as the basis for several predictions and expect the indicated probability level of the confidence limits to hold consistently. This results from the fact that the mathematical expression defining the probability level takes into account not only the variation in the dependent variable but also the sampling variation in the estimates of the regression coefficients and the standard deviation. If the original estimates are held constant and used repeatedly, the assumptions made in formulating the probability statement have been violated and the actual effectiveness of the statement is indeterminate. If, however, one adopts Mr. Kesler's "engineering view" and insures that predictions are being made about members of the population of concretes he sampled, a series of predictions based on a single estimate of the regression coefficients will probably result in relatively few errors of consequence.

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[1] Professor of Applied Mechanics, Kansas State College of Agriculture and Applied Science, Manhattan, Kan.

[2] Chief, Research Section, Division of Materials, Missouri State Highway Dept., Jefferson City, Mo.

MR. C. E. KESLER (*author*).—Mr. Scholer's discussion brings out an important point that evidently is not clear from the paper. The results given apply only to sound concrete made of the aggregates used in these particular tests and cured and tested as indicated. The relationship between compressive and flexural strengths would not only be influenced by deteriorating influences, but also various aggregates will give different results. A crushed stone aggregate should not be expected to give the same relationship as a well rounded gravel.

Mr. Willis' discussion is much appreciated and does clear up an apparently erroneous statement. The author's intent is correctly expressed in the second paragraph of Mr. Willis' discussion.

PETROGRAPHIC EXAMINATION OF CONCRETE AGGREGATE*

By Richard C. Mielenz[1]

Petrographic examination of concrete aggregate is visual examination and analysis of the material in terms of both lithology and properties of the individual particles. The procedure requires use of a hand lens and petrographic and stereoscopic microscopes; less commonly, X-ray diffraction or differential thermal analysis is a necessary part of the procedure. By petrographic examination, the relative abundance of specific types of rocks and minerals is established; the physical and chemical attributes of each, such as particle shape, surface texture, pore characteristics, hardness, and potential alkali reactivity, are described; coatings are identified and described; and the presence of contaminating substances is determined.

As will be discussed subsequently, petrographic examination contributes in several ways to the investigation, selection, testing, and control of aggregates. Consequently, the method is being progressively more widely applied. Since 1936, all aggregates used in concrete construction by the Bureau of Reclamation were examined petrographically as a part of the basis for their selection (**1**).[2] The method has been applied similarly by the Corps of Engineers since before 1940 (**2**). Techniques of petrographic examination are described in several papers published during and since 1946 (**1, 2, 3, 4, 5, 6**). Petrographic examination of aggregates is performed also in several other governmental agencies and state highway departments and may be obtained through commercial laboratories.

In 1952, the ASTM accepted a Tentative Recommended Practice for Petrographic Examination of Aggregates for Concrete (C 295),[3] and the procedure was adopted as standard in 1954. Reference to petrographic analysis is included in the Tentative Specifications for Concrete Aggregates (C 33).[4]

The abundant data obtained and the rapidity with which petrographic examination can be completed justify more general use of the method in investigation, selection, manufacture, and use of concrete aggregate.

This paper summarizes the objectives and applications of petrographic examination of aggregates with reference to gravel, sand, crushed stone, slag, and the most common types of lightweight aggregate. Techniques of the examination are treated very briefly because satisfactory instructions have been published (**2, 3, 6**) and are included in ASTM Recommended Practice C 295.[3]

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13–18, 1954.

[1] Head, Petrographic Laboratory, Bureau of Reclamation, Denver, Colo.

[2] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 1217.

[3] 1952 Book of ASTM Standards, Part 3, p. 978.

[4] 1952 Book of ASTM Standards, Part 3, p. 897.

PURPOSE OF THE PETROGRAPHIC EXAMINATION OF CONCRETE AGGREGATES

Preliminary Determination of Quality:

Preliminary petrographic examination of concrete aggregate is performed either in the field or in the laboratory as an adjunct to geologic examination, exploration, and sampling. As will be shown subsequently, the examination assists the geologist or materials engineer in determining the extent to which consideration of an undeveloped deposit is justified. Also, the preliminary petrographic examination indicates the relative quality of aggregates from alternate sites. By revealing variations in the material, examination of exposures or core from pilot drill holes establishes the minimum program of exploration and sampling necessary for acceptance or rejection of the deposit.

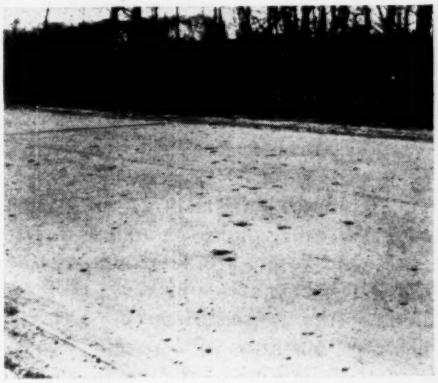
Establishing Properties and Probable Performance:

Petrographic examination is primarily a supplement to the acceptance tests. Probable performance of concrete aggregate is estimated in two general ways by petrographic examination. First, the examination reveals the composition and physical and chemical characteristics of the constituents. From this information, the probable response of the aggregate to such phenomena as attack by cement alkalies, freezing-thawing, wetting-drying, and heating-cooling, usually can be estimated. The rapidity with which the petrographic examination predicts potential alkali reactivity of aggregate is especially valuable because of the long time commonly required by tests of concrete or mortar.

Second, petrographic examination establishes the fundamental nature of aggregates so that aggregates from unfamiliar sources can be compared with aggregates upon which information is available. This application is discussed below.

Correlation of Samples with Aggregates Previously Tested or Used:

Detailed petrographic examination permits the comparison of samples with aggregates previously tested or used. This correlation can be made only by petrographic examination. Thus, data and experience previously obtained by use and time-consuming tests of similar aggregates can be applied in the selection of materials proposed for current work, even though the materials may not have come from the earlier used sources.



Courtesy of the Michigan State Highway Department.

FIG. 1.—Popouts Produced by Claystone, Shale, and Chert in Concrete Pavement near Jackson, Mich.

By relating the sample to aggregates previously used in construction, aggregate which is indicated to be unsound by standard tests may be found adequate, or conversely, aggregate indicated to be sound in standard tests might be found unsatisfactory for the intended use.

For example, gravel in certain deposits near Jackson, Mich. meets usual specification requirements for soundness, abrasion resistance, and content of soft particles, yet produces objectionable popouts in pavements after exposure for two winters (Fig. 1). Petrographic examination of the gravel and of particles producing popouts during service has revealed the identity of the unsound rock types. Examination of proposed materials will demonstrate the presence or absence of these rock types and thus will indicate, in the light of other data, whether the aggregate should be accepted, rejected, or subjected to special tests.

Selecting and Interpreting Other Tests:

All properties of aggregates influencing performance of concrete are not ordinarily evaluated by test prior to selection of the aggregate to be used in the work, primarily because of cost and time required. Such factors as thermal properties and volume change with wetting-drying rarely are determined. Other properties, such as chemical reactivity or effect of the aggregate on the freezing-thawing resistance of concrete, usually are not determined for lack of time or facilities. Consequently, it is worthwhile to apply a test by which the relative significance of such properties can be determined and the need for supplementary quantitative tests indicated.

Petrographic examination aids interpretation of other tests. For example, are the particles identified as clay lumps in accordance with ASTM Method C 142[5] indeed clay lumps or are they merely friable or pulverulent particles? What is the cause of unexpected failure of concrete specimens in freezing and thawing? Is it the presence of unsound particles which do not disintegrate in the sulfate soundness test, yet expand in freezing and thawing? Is it the result of alkali-aggregate reaction? Is failure in the soundness or abrasion test the result of complete breakdown of a small proportion of unsound or soft particles or partial disintegration of the greater proportion of the aggregate?

Detection of Contamination:

Petrographic examination is the best method by which deleterious and extraneous substances can be detected and determined quantitatively. Inadvertent contamination with natural substances, industrial products, or wastes, such as from overburden or from trucks or railroad cars not properly cleaned of previous cargo, may decrease the quality of aggregate markedly. Similar contamination introduced by containers may invalidate samples. Such substances as clay, soil, coal, vegetable matter, petroleum products, or refractories containing calcium or magnesium oxides are especially important. Contamination of synthetic aggregates also results from incomplete processing and consequent presence in the finished product of raw or partially fired raw materials or coal (Fig. 2).

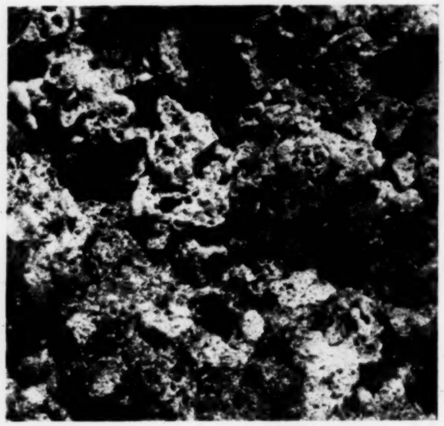


FIG. 2.—Coal in Sintered Clay Before Crushing (× 2.7) (reduced ½ in reproduction).

Undesirable substances that are inherent in the material, such as coatings, clay, plant remains, coal, and soluble salts, are detected easily and can be determined quantitatively by petrographic methods.

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[5] 1952 Book of ASTM Standards, Part 3, p. 935.

Determining Effects of Processing:

Petrographic examination aids in production and processing of aggregate. The relative merit of alternative processing methods and equipment can be determined quickly by comparison of the original material with the processed aggregate. Comparison can be based on particle shape, content of unsound or chemically reactive constituents, presence of coatings, or production of rock dust.

The feasibility of beneficiation by removal of unsound or deleterious constituents depends upon the properties of the particles and their abundance. By petrographic examination, the undesirable particles can be identified and separated. Their properties then can be evaluated and compared with properties of the remainder of the aggregate. If the particles are unusually soft, friable, dense, lightweight, or high in magnetic susceptibility, separation may be feasible on a commercial scale.

Petrographic examination can be used to control the manufacture of synthetic aggregate, such as expanded shale or clay, perlite, slag, and others. Examination and analysis by microscopy, X-ray diffraction, and differential thermal analysis reveal quantitatively the presence of raw or underburned materials; deleterious substances, such as free lime or magnesia; and alkali reactive phases or contaminants such as coal, in relation to processing equipment and methods.

PERFORMANCE OF THE PETROGRAPHIC EXAMINATION

Samples for Petrographic Examination:

Samples of aggregate for petrographic examination should be representative of the source. Recommended procedures for sampling and for preparation of the sample for analysis are covered by the ASTM Standard Methods of Sampling Stone, Slag, Gravel, Sand, and Stone Block for use as Highway Materials (D 75)[6] and the Recommended Practice for Petrographic Examination of Aggregates for Concrete (C 295).[3]

The petrographic examination may be performed in a preliminary way in the field as an adjunct to geologic examination, exploration, and sampling, or in the laboratory as a part of the program of testing and selection.

Examination in the Field:

Petrographic analysis of samples in the field usually is qualitative or only semiquantitative because lack of facilities makes detailed work difficult. However, detailed examination in the field may be warranted if very coarse aggregate (for example, that retained on the 3-in. sieve) is to be used in the work, inasmuch as a representative sample of this size fraction necessarily weighs several hundred pounds and transportation of the sample to the laboratory is costly. Chips from cobbles not adequately identified by the hand lens are taken to the laboratory for further study.

If the deposit or rock formation is variable, samples should be selected from each zone, and detailed notes made at the site should relate each sample to a particular zone and portion of the deposit or formation. The relative proportion of unsound, fractured, or chemically deleterious materials should be estimated from measurements made at exposures. These notes and the results of the tests on the samples will be the basis for operation of the deposit inasmuch as it may be desirable to waste or avoid zones or portions containing inferior or unsuitable materials.

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[6] 1952 Book of ASTM Standards, Part 3, p. 949.

Examination in the Laboratory:

Petrographic examination of aggregate in the laboratory may be brief or detailed. Brief examination indicates the relative merit of materials from alternate sources and supplies justification for abandonment or continued investigation of undeveloped deposits. The preliminary examination should not replace the quantitative analysis included in the program of acceptance tests.

Samples supplied to the laboratory comprise: (1) granular materials, such as gravel, sand, crushed stone, slag, or synthetic aggregate; (2) quarried stone in blocks and irregular pieces; or (3) drilled core. For granular materials, the examination should be performed on all size fractions included in the aggregate. The sample of each size fraction should comprise a minimum of 300 particles. For natural sand and gravel and crushed stone, the minimum representative samples are as follows:

Size fraction	Weight of 300 particles
3 to 1½ in.	57 lb
1½ to ¾ in.	19 lb
¾ to ⅜ in.	2.6 lb
⅜ to $\frac{3}{16}$ in.	0.75 lb
No. 4 to 8	15 g
No. 8 to 16	2.1 g
No. 16 to 30	0.28 g
No. 30 to 50	0.033 g
No. 50 to 100	0.0066 g

Samples for petrographic examination are obtained by sieving in accordance with the ASTM Standard Method of Test for Sieve Analysis of Fine and Coarse Aggregates (C 136)[7] and the Standard Method of Test for Amount of Material Finer than No. 200 Sieve in Aggregates (C 117).[8] The fractions are quartered or, for fine aggregate, split repeatedly on an appropriate riffle. Specially calibrated and fabricated cups holding 100 grains in the various size fractions have proved convenient in the Petrographic Laboratory of the Bureau of Reclamation for obtaining the small samples of fine aggregate for the analysis.

Details of procedure are outlined by Mather and Mather (2) and in ASTM Recommended Practice C 295.[3]

During the analysis, helpful clues to identity and physical condition can be obtained by noting such features as: (1) friability or pulverulence in the fingers; (2) resonance when struck; (3) ease of fracturing; (4) nature of the fracture surface and fracture fillings; (5) odor on fresh fracture; (6) color and its variation; (7) internal structure, such as porosity, granularity, or lamination; and (8) reaction to water, such as absorption of droplets on fresh fracture, evolution of air on immersion, capillary suction against the tongue, slaking, softening, or swelling.

FIG. 3.—Performing the Petrographic Examination of Aggregate with the Stereoscopic Microscope.

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[7] 1952 Book of ASTM Standards, Part 3, p. 954.

[8] 1952 Book of ASTM Standards, Part 3, p. 933.

Fractions retained on the No. 30 sieve are best identified, examined, and counted under the stereoscopic microscope (Fig. 3). The finer fractions usually are identified most easily in immersion oils under the petrographic microscope. However, better continuity in the analysis is obtained if analysis of fractions passing the No. 30 sieve and retained on the No. 100 sieve is performed under the stereoscopic microscope.

Thin sections occasionally are necessary in examination of natural aggregate. They usually are employed in the study of quarried stone. Thin sections or polished surfaces always should be used in analysis of blast-furnace slag. X-ray diffraction and differential thermal analysis may be required to identify or determine quantitatively constituents that are finely divided or dispersed through particles of aggregate (Fig. 4).

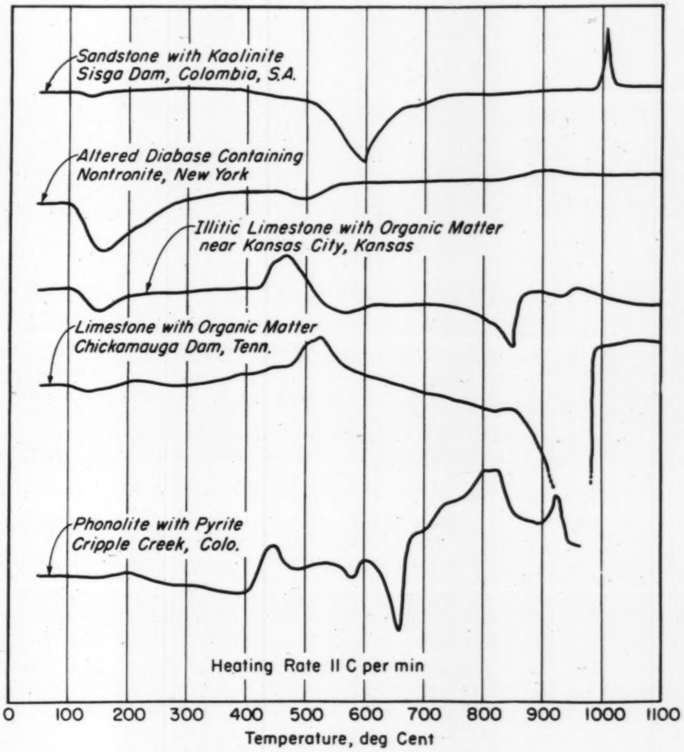


FIG. 4.—Typical Differential Thermal Analysis Records Obtained on Concrete Aggregates.

Kaolinite is indicated by the endotherm (downward shift) at 500 to 730 C and the exotherm (upward shift) at 990 to 1025 C. Nontronite is revealed by endotherms at 100 to 350 C and 450 to 550 C. Illite produces the small endotherms at 100 to 200 C and 500 to 615 C. Organic matter produces large exotherms at 430 to 500 C or 440 to 600 C. Pyrite develops a marked exotherm at 400 to 485 C.

Ordinarily, analysis is performed on at least three size fractions of coarse aggregate and six size fractions of fine aggregate. The results may be used to compute the petrographic composition of the aggregate in any gradation comprising the analyzed fractions. Occasionally, one analysis only may be performed on a graded aggregate. For such an analysis, the composition by count usually differs greatly from the composition by weight.

Numerical results of the analysis may be expressed by weight or count for particles retained on the No. 30 sieve, but for the finer fractions, the results are based only upon count of grains unless a correction factor is applied. Consequently, consistent analyses of all fractions of fine and coarse aggregate can be reported only by count. Analysis by count is the more appropriate technically because the influence of particles of given type upon performance of concrete depends primarily upon their frequency and distribution in the mass. However, when applied to coarse aggregate only, the petrographic analysis is more rapid if the relative proportion of the several rock types or facies is determined by weight.

Details of calculating and reporting are summarized in ASTM Recommended Practice C 295.[3]

Observations Included in the Petrographic Examination:

In reporting the results of the petrographic examination, the petrographer should supply information on the following subjects as necessary to evaluation of the aggregate:

- Mineralogic and lithologic composition
- Particle shape
- Surface texture
- Fracturation
- Coatings
- Porosity, permeability, and absorption
- Volume change, softening, and disintegration with wetting and drying.
- Thermal properties
- Strength and elasticity
- Density
- Hardness
- Chemical activity
  - Solubility
  - Oxidation, hydration, and carbonation
  - Sulfates
  - Cation exchange reactions
  - Organic substances
  - Alkali reactivity

The significance of these properties is discussed by Rhoades and Mielenz (**4, 5**).

It is intended that the properties indicated above be determined qualitatively by observation of the mineralogic composition and texture of the particles or by simple tests, if appropriate. If other test data are available or if the particles can be compared petrographically with previously tested materials, the properties can be evaluated semiquantitatively or quantitatively.

Condition of the Particles:

The following classification of properties is that used by the Bureau of Reclamation to catalogue the physical and chemical condition of particles constituting an aggregate. Physical condition is defined by three terms: satisfactory, fair, and poor; chemical stability in concrete is designated by two terms: innocuous and deleterious, as follows:

Satisfactory.—Particles are hard to firm, relatively free from fractures, and not flat or chiplike; capillary absorption is very small or absent, and the surface texture is relatively rough.

Fair.—Particles exhibit one or two of the following qualities: Firm to friable; moderately fractured; capillary absorption small to moderate; flat or chiplike; surface relatively smooth and impermeable; very low compressibility; coefficient of thermal expansion approaching zero or being negative in one or more directions.

Poor.—Particles exhibit one or more of the following qualities: Friable to pulverulent; slake when wetted and dried; highly fractured; capillary absorption moderate to high; marked volume change with wetting and drying; combine three or more qualities indicated under "fair."

Innocuous.—Particles contain no constituents which will dissolve or react chemically to a significant extent with constituents of

TABLE I.—EXAMPLE OF TABULATION OF A PETROGRAPHIC ANALYSIS OF GRAVEL.
———— Plant, ———— Company, Near Denver, Colo.
Sample No. ————

Rock Types	Size Fraction, per cent by weight[a]			Description of Rock Types	Physical Quality	Chemical Quality
	1-½ to ¾ in.	¾ to ⅜ in.	⅜ to 3⁄16 in.			
Granite	29.5	40.0	48.6	Medium- to fine-grained, rounded to fragmental	Satisfactory	Innocuous
Weathered granite	12.0	17.7	17.2	Fractured, weathered, rounded to fragmental	Fair	Innocuous
Deeply weathered granite	...	0.5	...	Fractured, slightly friable, rounded to fragmental	Poor	Innocuous
Coarse-grained granite	6.4	6.1	8.4	Pink, rounded, includes some free quartz	Satisfactory	Innocuous
Fractured coarse-grained granite	...	0.9	...	Pink, rounded, includes some free quartz	Fair	Innocuous
Rhyolite porphyry	0.8	0.2	1.1	Microcrystalline, porphyritic, white to brown	Satisfactory	Innocuous
Andesite porphyry	2.2	1.2	0.1	Microcrystalline, porphyritic, tan to green	Satisfactory	Innocuous
Weathered andesite porphyry	...	0.3	...	As above, fractured and weathered	Fair	Innocuous
Basalt	0.2	...	0.6	Weathered, fractured, black, microcrystalline	Fair	Innocuous
Diorite	0.4	0.4	0.1	Medium- to fine-grained, hard, massive	Satisfactory	Innocuous
Granite gneiss	32.3	14.3	15.8	Hard, banded, fine- to medium-grained	Satisfactory	Innocuous
Weathered gneiss	10.3	7.8	2.7	As above, fractured to slightly friable	Fair	Innocuous
Deeply weathered gneiss	0.2	...	...	As above, intensely fractured to friable	Poor	Innocuous
Schist	2.2	2.3	2.2	Hornblende schists, hard, rounded	Satisfactory	Innocuous
Fractured schist	...	0.4	0.2	As above, fractured	Fair	Innocuous
Quartzite	2.8	6.2	2.0	Fine-grained, hard, massive to schistose	Satisfactory	Innocuous
Milky quartz	0.6	1.0	0.5	Massive, hard, brittle, dense, smooth	Fair	Innocuous
Quartzose sandstone	...	0.1	...	Fine-grained, massive, firm to hard	Satisfactory	Innocuous
Ferruginous sandstone	...	0.4	...	Porous, brown, platy, quartzose	Fair	Innocuous
Shale	...	0.2	0.5	Soft, absorptive, rounded, gray	Poor	Innocuous
Rhyolite	0.2	...	...	Cryptocrystalline, porphyritic, pink to gray	Satisfactory	Deleterious

[a] Based upon analysis of 19.0 lb of 1½- to ¾-in., 2.7 lb of ¾- to ⅜-in., and 0.80 lb of ⅜- to 3⁄16-in. aggregate.

the atmosphere, water, or hydrating portland cement while enclosed in concrete or mortar under ordinary conditions.

Deleterious.—Particles contain one or more constituents in significant proportion which are known to react chemically under conditions ordinarily prevailing in portland-cement concrete or mortar in such a manner as to produce significant volume change, interfere with the normal course of hydration of portland cement, or supply substances which might produce harmful effects upon mortar or concrete.

TABLE II.—EXAMPLE OF TABULATION OF A PETROGRAPHIC ANALYSIS OF NATURAL SAND.

———— Plant, ———— Company near Denver, Colo.
Sample No. ————

Constituents	Amount, as number of particles in per cent												
	In Size Fractions Indicated[a]							In Whole Sample[b]					
	No. 4-8	No. 8-16	No. 16-30	No. 30-50	No. 50-100	No. 100-200	Passing No. 200	Physical quality			Chemical quality		
								S[c]	F[c]	P[c]	I[c]	D[c]	T[c]
Granite and granite gneiss	34.9	33.6	21.0	4.8	...	...	...	13.5	1.0	0.6	15.1	...	15.1
Pegmatite	34.2	28.7	2.0	...	...	...	...	8.2	0.8	0.2	9.2	...	9.2
Rhyolite tuff	0.8	0.9	0.3	...	...	...	...	0.3	...	...	...	0.3	0.3
Basalt	...	1.0	...	...	...	...	...	0.2	...	...	0.2	...	0.2
Sericite schist	2.4	0.7	...	9.5	11.2	1.1	...	4.7	...	...	4.7	...	4.7
Quartz and quartzite	24.6	41.2	59.2	65.0	43.0	48.8	28.8	51.6	...	...	51.6	...	51.6
Feldspar	2.6	3.3	16.7	11.1	18.7	23.8	10.5	...	11.4	...	11.4	...	11.4
Claystone	0.5	...	...	...	...	1.2	...	...	...	0.2	0.2	...	0.2
Chalcedonic chert	...	0.6	...	3.3	...	...	...	1.2	...	...	...	1.2	1.2
Mica	...	...	0.8	6.3	10.2	8.3	51.1	...	3.8	...	3.8	...	3.8
Hornblende, garnet, zircon, etc	...	...	...	...	16.9	16.8	9.6	2.3	...	...	2.3	...	2.3
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	82.0	17.0	1.0	95.5	1.5	100.0

[a] Based on count of 500 particles in each sieve fraction.

[b] Based on gradation of the sample received, and on the distribution of constituents by size fractions shown at the left above.

[c] S = Satisfactory; F = Fair; P = Poor; I = Chemically innocuous; D = Potentially chemically deleterious; T = Total of constituent in whole sample.

Coatings should be evaluated separately inasmuch as coatings usually are confined to portions of a deposit and, for crushed stone, the nature and abundance of coatings varies with processing methods and equipment.

Summarizing the Petrographic Examination:

Tables I, II, III, and IV exemplify a variety of forms in which the petrographic analysis may be reported. All are based upon samples received as a part of engineering investigations. The tabulations always are accompanied by appropriate discussion and supplementary description. Table I is in the form generally employed by the Bureau of Reclamation (7). It departs somewhat from the format recommended in ASTM Practice C 295,[3] but the inclusion of pertinent description simplifies interpretation of the analysis. The summary of physical and chemical quality is included in a separate tabulation.

TABLE III.—EXAMPLE OF TABULATION OF A PETROGRAPHIC ANALYSIS OF EXPANDED CLAY AGGREGATE.

———————— Plant, ———————— Company
Sample No. ————————

Constituent	Amount, as number of particles in per cent									Remarks
	In size fractions indicated[a]								In whole sample[b]	
	¾ to ⅜ in.	⅜ to $\frac{3}{16}$ in.	No. 4–8	No. 8–16	No. 16–30	No. 30–50	No. 50–100	Passing No. 100		
Black to gray, vesicular particles......	44.6	30.2	36.2	44.1	46.5	55.0	62.2	64.4	42.4	Vesicular, hard
Black to gray, vesicular particles......	13.1	1.7	...	...	...	...	...	...	1.2	Vesicular, friable
Red to tan, vesicular particles.........	26.1	29.5	20.2	25.0	15.4	24.0	21.8	20.6	23.5	Vesicular, hard
Red to tan, vesicular particles.........	7.7	1.8	...	...	...	...	...	...	0.8	Vesicular, friable
Red to brown, brick-like particles......	4.9	23.6	32.3	22.0	25.6	12.4	7.8	4.9	21.3	Not vesicular, firm to fragile
Gray to pink, brick-like particles......	2.8	9.8	7.7	8.8	9.2	3.0	1.6	1.1	7.1	Not vesicular, fragile, many slake in water
Gray to pink, brick-like particles......	0.6	1.0	0.4	...	...	...	...	...	0.4	Not vesicular, friable, many slake in water
Gray to black, friable particles.........	...	1.7	2.0	...	0.8	0.3	...	...	1.0	Not vesicular, contain coal
Granite............	0.2	0.4	0.4	...	1.4	2.8	4.7	7.0	1.4	Hard, dense
Sandstone..........	...	0.2	...	...	...	...	...	...	0.1	Hard, fine-grained
Coal...............	...	0.1	0.8	0.1	1.1	2.5	1.9	2.0	0.8	Hard to friable
Total...........	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	

[a] Based on count of 500 particles in each size fraction.

[b] Based on gradation of the sample received, and on the distribution of constituents by size fractions shown at left above.

Table II is the analysis of the sand produced with the gravel whose composition is summarized in Table I. The format accords with ASTM Recommended Practice C 295.[3] Table III is similar except that the designations of quality are not used because they are inappropriate for description of lightweight aggregate.

Table IV is an analysis of a sample representing a commercial crushed stone coarse aggregate passing the $1\frac{1}{2}$ in. sieve. The analysis was obtained because the aggregate apparently retarded or prevented development of specified strength by the concrete under certain conditions. In the tabulation, the denotation of "innocuous" and "deleterious" is restricted to potential deleterious alkali reactivity because the significance of the sulfides and organic matter in the stone could not be evaluated.

PETROGRAPHIC EXAMINATION OF NATURAL AGGREGATES

Examination of Natural Aggregates in the Field:

Sand and gravel result from weathering and natural abrasion of rock and the deposition of the resulting particles along streams, in lakes or marine basins, or by wind or glaciers on the earth's surface. Consequently, sand and gravel are more or less complex mixtures of different kinds of rocks and minerals. Moreover, deposits of sand and gravel usually vary vertically by stratification and laterally because of the lenticular nature of zones or strata. The concrete-making qualities of the aggregate are influenced by these changes.

TABLE IV.—EXAMPLE OF TABULATION OF A PETROGRAPHIC ANALYSIS OF CRUSHED STONE COARSE AGGREGATE.[a]

——————— Plant, ——————— Company
Sample No. —————

Rock Type or Facies	Description of the Rock Type or Facies	Amount, per cent by weight[b]					
		Physical Quality			Chemical Quality		
		S[c]	F[c]	P[c]	I[c]	D[c]	T[c]
Dense dolomitic limestone....	Gray to buff, contains sparse organic matter with pyrite and marcasite	56.2	...	...	56.2	...	56.2
Soft dolomitic limestone.....	Gray to buff, soft to friable, slightly porous, sparse organic matter with pyrite and marcasite	...	33.9	...	33.9	...	33.9
Soft, organic dolomitic limestone..................	Same as above except containing one or more seams of iron sulfides and organic matter	...	4.2	...	4.2	...	4.2
Limestone................	White to gray, coarse- to medium-grained	2.4	...	...	2.4	...	2.4
Laminated limestone........	Laminated, fine-grained, iron sulfides and organic matter abundant	...	2.1	...	2.1	...	2.1
Chalcedonic limestone.......	White to gray, particles or zones of chalcedony evident	1.0	...	...	...	1.0	1.0
Chalcedonic chert	Conchoidal fracture, dense	...	0.1	...	...	0.1	0.1
Sandstone..................	Includes also grains of quartz and feldspar	0.1	...	...	0.1	...	0.1
Total.....................		59.7	40.3	...	98.9	1.1	100.0

[a] Sample graded in accordance with specifications of the ——————— State Highway Department for 1½ in. to No. 4 aggregate for concrete highway pavement.

[b] Based upon analysis of 25.9 lbs of aggregate split from the sample.

[c] S = Satisfactory; F = Fair; P = Poor; I = Not deleteriously alkali reactive; D = Potentially deleteriously alkali reactive; T = Total of constituent in the sample.

Examination in the field should reveal the variability of the deposit, especially with reference to unsound or deleterious particles, clay, and organic matter.

Deposits of sand and gravel commonly are changed by deposition of mineral matter from ground water or by weathering of the particles. Examination in the field should indicate the lateral and vertical extent and the physical nature of the coatings. Areas of the deposit free from coatings and zones so heavily coated as to preclude processing should be delineated.

Weathering of gravel and sand after formation of the deposit is common on terraces and at lower levels of deposits along existing stream channels. The examination should indicate the extent and distribution of such weathering.

Close observation of gravel and sand exposed on the surface of the deposit commonly will reveal unsound particles which slake or fracture with freezing-thawing or wetting-drying (Fig. 5). Identification of such particles will aid evaluation of the petrographic examination performed in the laboratory. Representative specimens of such particles should be packaged separately and transmitted to the laboratory with samples of the gravel and sand. Water-soluble salts in coatings or ground water also may be revealed by efflorescence at or near the surface of the deposit. Their presence forewarns of the need for quantitative determination of their concentration in the aggregate.

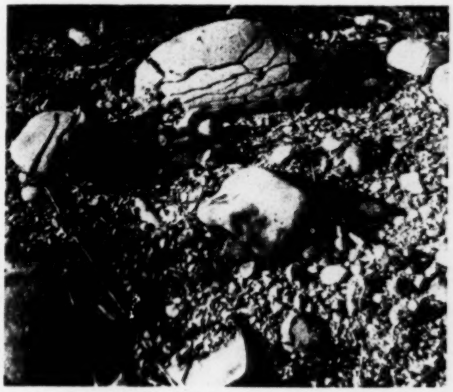
Examination of Natural Aggregates in the Laboratory:

Samples and data from the field should be examined to determine: (1) the abundance of individual lithologic or mineralogic types; (2) the abundance of particles in various physical conditions and degrees of chemical reactivity; (3) the composition, frequency, abundance, and physical nature of coatings; and (4) in a qualitative way, the possible contribution of particles of the several types to properties of concrete (Tables I and II).

Natural aggregates may contain more than 20 rock and mineral types. Consequently, petrographic examination commonly is time-consuming. Based upon the similarity in composition and probable performance in concrete, two or more rock types commonly can be combined into a single category with considerable saving in time and without loss in validity of the analysis. For example, granites, quartz monzonites, and granite gneisses or rhyolites, dacites, and latites of similar composition and physical condition might be combined, thus eliminating the need for tedious examination sufficient to effect a separation.

Soft and altered particles may be original constituents of sand and gravel, others are developed by weathering in the deposit. Weathering in the deposit is especially significant because the alteration affects most or all particles, causing softening and absorptivity in the superficial portion of the particles. This action decreases both the bond with cement and the strength and durability of the concrete.

Coatings on gravel and sand vary from minute spots and films to a cement which produces zones of sandstone or conglomerate in the deposit. Coatings usually are composed of silt, clay, and



Courtesy of the Michigan State Highway Department.

FIG. 5.—Cobbles of Argillaceous Limestone Disrupted by Freezing-Thawing in the Deposit, near Charlesvoix, Mich.

Observation of natural disintegration forewarns of possible difficulty in service.

calcium carbonate; but organic matter, iron oxides, opal, manganiferous substances, alkali and alkali-earth sulfates, and soluble phosphates have been identified (**5**, **8**). The petrographic examination should reveal the composition, abundance, physical properties, probable potential chemical reactivity, and the ease with which the coatings are removed by impact and abrasion.

Potentially alkali reactive gravel and sand occur along many important rivers in the United States and have been responsible for serious distress in many concrete structures (Fig. 5). The location of many known deposits of alkali reactive natural aggregate in western United States has been reported by Holland and Cook (**9**). The known alkali reactive substances are the silica minerals, opal, chalcedony, tridymite, and cristobalite; glassy to cryptocrystalline rhyolites, dacites, latites, and andesites, and their tuffs; at least certain artificial siliceous glasses; and at least certain phyllites. Any rock containing a significant proportion of these substances is potentially deleteriously reactive.

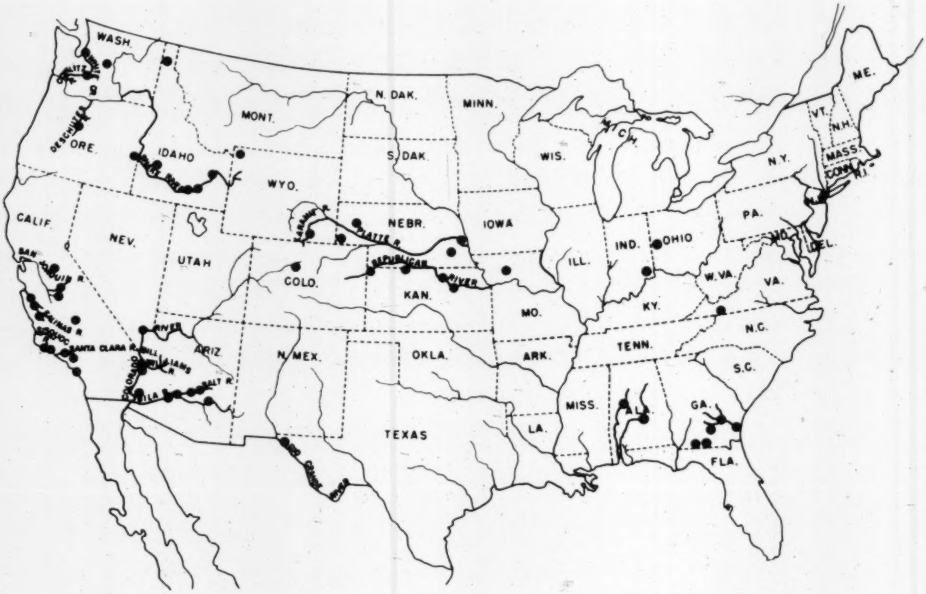

WASH.
COWLITZ
ORE.
DESCHUTES
IDAHO
MONT.
N. DAK.
MINN.
S. DAK.
WYO.
CALIF.
NEV.
UTAH
LARAMIE R.
NEBR.
PLATTE R.
IOWA
REPUBLICAN
RIVER
COLO.
KAN.
SAN JOAQUIN R.
SALINAS R.
SANTA CLARA R.
RIVER
ARIZ.
COLORADO
WILLIAMS R.
SALT R.
GILA
N. MEX.
OKLA.
TEXAS
WIS.
MICH.
ILL.
IND.
OHIO
MO.
ARK.
MISS.
LA.
TENN.
KY.
W. VA.
VA.
N.C.
S.C.
GA.
FLA.
PA.
N.Y.
MD.
DEL.
N.J.
ME.
VT.
N.H.
MASS.
CONN.
R.I.

FIG. 6.—Location of Structures in the United States Known to be Affected by Alkali-Aggregate Reaction in Concrete, and Rivers Known to Carry Reactive Sand or Gravel.

PETROGRAPHIC EXAMINATION OF CRUSHED STONE

Examination of Stone in the Field:

Rock formations are massive or stratified; the strata can occur in any attitude with respect to the horizontal; and rock may vary widely in porosity, hardness, toughness, or degree of fracturing. Rock formations commonly contain zones of faulting, jointing, or local shearing, within which the materials are fractured or chemically decomposed. Certain zones may contain deleterious or unsound substances, such as chalcedonic or opaline chert and clay or shale in limestone or dolomite. Especially in warm humid areas, rock formations commonly are fractured, leached, and partially decomposed near the surface.

These features should be discovered by geologic and petrographic examination of natural exposures, quarried faces or other excavations, and drilled core. Petrographic examination in the field should include scrutiny of portions of the formation, excavated material, or stone previously used in the area for fill, ballast, riprap, or other construction. This may reveal unsound portions which have failed in the natural exposure to freezing-thawing or wetting-drying or to oxidation and hydration (Fig. 7). For example, disintegrated granite commonly appears sound on fresh exposure, yet disintegrates rapidly thereafter. The Chiplima granite considered for use as aggregate in construction of Hirakud Dam, India, appeared satisfactory immediately following blasting, but after one monsoon season, was stained brown and microfractures were evident as the result of oxidation of jarosite ($K_2Fe_6(OH)_{12}(SO_4)_4$), releasing iron oxides and soluble sulfates. Disintegration of rock on natural exposure commonly does not coincide with results of the sulfate soundness tests (10). Shale, claystone, and argillaceous rocks may slake and fracture following exposure. Soluble salts usually will be revealed by efflorescence at exposed surfaces.

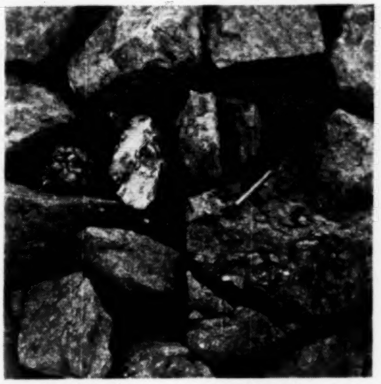


FIG. 7.—Disintegration of Argillaceous Facies of Limestone Used as Riprap at Chickamauga Dam, Tenn.

Observation of such disintegration indicates unsoundness of stone in at least portions of a quarry.

Examination of Crushed Stone in the Laboratory:

As is indicated above, crushed stone aggregates commonly are complex petrographically. Consequently, they should be examined in the detail required for natural aggregate (Table IV).

Petrographic examination of quarried stone in the form of blocks or irregular pieces should include inspection of the entire sample. The examination should be performed in a manner analogous to the petrographic examination of coarse aggregate to establish the relative abundance of individual rock types or facies. Specimens representative of each type should be obtained by sawing or coring of typical pieces; these specimens serve for special tests, detailed petrographic examination, and reference.

If the sample of stone was submitted for crushing tests in the laboratory, samples of the aggregate produced by the crushing processes employed also should be subjected to petrographic examination. This will establish the significance of fracturation and internal texture on particle size and shape; frequency of fractures and seams within the particles; distribution of unsound or deleterious substances in the size fractions; and the abundance and composition of crusher dust. These qualities should be correlated with the processing equipment and methods employed.

Inspection of the stone prior to processing is important because only thus can the examination of the finished aggregate be interpreted fully. For example, if unsound or deleterious particles constitute 10 per cent of the finished aggregate, was this proportion derived from approximately one piece in ten of the original sample, or does a typical piece of the stone contain approximately 10 per cent of unsound material? The former possibility suggests that the quarry should be examined to determine whether the unsound zones can be avoided or wasted; the latter suggests that the material should not be used as aggregate in permanent construction.

If the samples are in the form of drilled core, the entire length of core should be examined and compared with logs available from the driller and geologist. Especial attention must be given sections in which core loss was high or complete, inasmuch as such zones commonly represent fractured, altered, or otherwise unsound rock. The core should be examined by means of the hand lens, stereoscopic microscope, and petrographic microscope, as necessary, to establish variations in lithology; frequency and intensity of fracturation; content of clay and shale, regardless of rock type; and presence of deleterious substances, such as sulfides, soluble salts, and alkali reactive substances. These observations should be correlated from hole to hole so that the variation in lithology or quality of the rock, both in depth and laterally, is established.

The quality of the aggregate to be expected from the formation represented by the core also will be indicated by crushing tests and subsequent petrographic examination of the aggregate.

PETROGRAPHIC EXAMINATION OF BLAST-FURNACE SLAG

Blast-furnace Slag:

Blast-furnace slag is the nonmetallic product, consisting essentially of silicates and aluminosilicates of calcium and of other cations, which is developed simultaneously with iron in a blast furnace (see ASTM Specifications C 125).[9] Three general types of blast-furnace slag are used for concrete aggregates, namely, air-cooled slag, granulated slag, and lightweight slag (11). Petrographic examination of lightweight slag will be discussed in a later section.

Performance of the Petrographic Examination of Blast-Furnace Slag:

The procedure for petrographic examination of blast-furnace slag is not included specifically in ASTM Recommended Practice C 295.[3] However, the instructions provided for examination of ledge rock, crushed stone, and manufactured sand are applicable. In addition to the indicated microscopical methods, polished and etched surfaces for study in reflected light are a valuable technique, being preferred by some petrographers over thin sections because of the ease of preparation, greater area, and two-dimensional aspect.

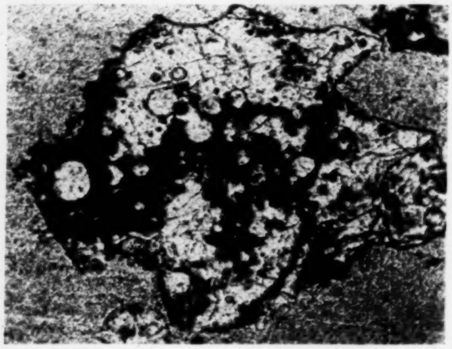


FIG. 8.—Photomicrograph of Granulated Blast-furnace Slag. Note the vesicles (bubbles) in the glass phases (white) (× 80) (reduced ½ in reproduction).

The dark areas are concentrations of microcrystalline melilite and merwinite.

Air-cooled slag is more or less well crystallized, depending primarily upon the method of disposal employed at the steel plant. Such slag crushes to angular and approximately equidimensional pieces whose surface texture is pitted, rough, or conchoidal. Crystals range from submicroscopical to several millimeters in size. Abrasion resistance relates to glass content and the condition of internal stress (**11**). Well-granulated slag is substantially all glass; crystals occur individually or in clusters scattered through the glass matrix. Incipient crystallization produces brown or opaque areas in thin section (Fig. 8).

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[9] Standard Definitions of Terms Relating to Concrete and Concrete Aggregates (C 125 – 48), 1952 Book of ASTM Standards, Part 3, p. 990.

The petrographic examination of blast-furnace slag aggregate should include description of the various types of slag as well as of contaminating substances. The slag constituent usually can be segregated into two or more varieties, depending upon particle shape, surface texture, color, vesicularity, crystallinity, or presence of products of weathering. Each type should be studied in some detail to assure identification of potentially deleterious compounds.

More than 20 compounds have been identified in blast-furnace slag (Table V), but even well-crystallized slag rarely contains more than five compounds (Table VI). The commonest crystalline constituent of blast-furnace slag is melilite, a compound between akermanite ($2CaO \cdot MgO \cdot 2SiO_2$) and gehlenite ($2CaO \cdot Al_2O_3 \cdot SiO_2$). High-lime blast-furnace slags commonly contain one or more forms of calcium disilicate (α', β or γ forms of $2CaO \cdot SiO_2$). Magnesian blast-furnace slags usually contain monticellite, forsterite, or merwinite. Calcium sulfide almost always is present in small proportion. Sulfides of manganous manganese and ferrous iron are common. Properties and techniques for identification of these compounds are summarized by Rigby (**12**), Nurse and Midgley (**13**), and Snow (**14, 15**), and in standard works on mineralogy. X-ray diffraction methods are necessary if crystalline phases are submicroscopical and are a great aid if a petrographer is developing experience independently in this field.

TABLE V.—COMPOUNDS OCCURRING IN BLAST-FURNACE SLAG.

Compound	Chemical Formula	Compound	Chemical Formula
Gehlenite	$2CaO \cdot Al_2O_3 \cdot SiO_2$	Oldhamite	CaS
Akermanite	$2CaO \cdot MgO \cdot 2SiO_2$	Ferrous sulfide	FeS
Pseudowollastonite	$\alpha CaO \cdot SiO_2$	Manganous sulfide	MnS
Wollastonite	$\beta CaO \cdot SiO_2$	Spinel	$(Mg, Fe)O \cdot Al_2O_3$
Bredigite	$\alpha' 2CaO \cdot SiO_2$	Anorthite	$CaO \cdot Al_2O_3 \cdot 2SiO_2$
Larnite	$\beta 2CaO \cdot SiO_2$	Periclase	MgO
γ-dicalcium silicate	$\gamma 2CaO \cdot SiO_2$	Lime	CaO
Olivine	$2(Mg, Fe)O \cdot SiO_2$		
Merwinite	$3CaO \cdot MgO \cdot 2SiO_2$	Cristobalite	SiO_2
Rankinite	$3CaO \cdot 2SiO_2$	Calcium aluminate	$CaO \cdot Al_2O_3$
Monticellite	$CaO \cdot MgO \cdot SiO_2$	Cordierite	$2MgO \cdot 2Al_2O_3 \cdot 5SiO_2$
Pyroxene			
Diopside	$CaO \cdot (Mg, Fe)O \cdot 2SiO_2$	Sillimanite	$Al_2O_3 \cdot SiO_2$
Enstatite	$MgO \cdot SiO_2$	Mullite	$3Al_2O_3 \cdot 2SiO_2$
Clinoenstatite	$MgO \cdot SiO_2$	Madisonite	$2CaO \cdot 2MgO \cdot Al_2O_3 \cdot 3SiO_2$

[a] Compiled from several sources, primarily Nurse and Midgley (**13**), McCaffery *et al* (**17**) and American Concrete Institute Committee 201 (**33**).

Several original constituents of blast-furnace slag may be deleterious to the performance of concrete. Sulfides or their alteration products might affect adversely the hydration of the portland cement. Presence of colloidal sulfides is suggested by yellow or brown coloration of the glass phase (**11**). Inversion of β

dicalcium silicate to the γ dicalcium silicate, with the accompanying 10 per cent increase in volume of the crystals, causes "dusting" or "blowing" of slag (**11, 16**). The inversion ordinarily takes place before the slag has cooled, and the disintegrated material is removed by screening in the production of coarse aggregate.

In less severe occurrences the disintegration takes place slowly, producing pieces that are partly or wholly weak and friable. Such slag is not considered suitable for concrete aggregate. Dicalcium silicate can be identified microscopically in slag by special techniques (**16**). This action of dicalcium silicate can be avoided by maintaining a ratio of CaO to SiO_2 in the slag sufficiently low to prevent formation of the compound, or by chilling the molten slag so that the compound does not crystallize (**11**). If air-cooled slag is poured in thin layers, rapid cooling ordinarily arrests the compound in the β modification.

TABLE VI.—MOST FREQUENTLY OCCURRING COMBINATIONS OF COMPOUNDS OF $CaO \cdot MgO \cdot Al_2O_3 \cdot SiO_2$ PRODUCED BY CRYSTALLIZATION OF BLAST-FURNACE SLAG.[a]

Flux Stone	Combination of Compounds[b]												
	C_2AS	C_2MS_2	C_2S	CS	C_3S_2	C_3MS_2	MA	CMS_2	CMS	CAS_2	M_2S	MS	MgO
Limestone	X	X	X		X								
	X	X	X			X							
	X	X				X	X						
	X	X					X			X			
	X	X		X						X			
Dolomite		X		X				X		X			
		X						X		X	X		
		X					X			X	X		
		X					X		X		X		
		X				X	X		X				
						X	X		X				X
								X		X	X	X	

[a] After Nurse and Midgley (**13**).

[b] Key:
C_2AS = gehlenite } melilite
C_2MS_2 = akermanite } melilite
C_2S = dicalcium silicate
CS = wollastonite or pseudowollastonite
C_3S_2 = rankinite
C_3MS_2 = merwinite
MA = spinel
CMS_2 = diopside
CMS = monticellite
CAS_2 = anorthite
M_2S = forsterite
MS = enstatite
MgO = periclase

Free-lime (CaO) and magnesia (MgO) are not common in air-cooled blast-furnace slag and are not likely to form either as a primary phase or devitrification product in granulated blast-furnace slag (**13**). Nevertheless, their absence or presence and abundance should be established by the petrographic examination. These compounds are deleterious because of the increase in solid volume resulting from hydration or carbonation in place. Cristobalite has been reported as a constituent of blast-furnace slag (**17**). This compound is potentially alkali reactive; if identified, its abundance should be determined. The glass phase of normal blast-furnace slag is not deleteriously reactive with cement alkalies.

Contaminating substances whose presence or absence should be established by petrographic examination are metallic iron, iron carbide, coke, and incompletely fused fluxstone. The last is important because delayed hydration and carbonation of free lime and magnesia may produce expansion of the concrete and popouts. Metallic iron and iron carbides rust by oxidation and hydration if exposed at the surface of concrete.

PETROGRAPHIC EXAMINATION OF LIGHTWEIGHT CONCRETE AGGREGATES

Expanded Clay, Shale, and Slate:

Petrographic examination of lightweight aggregate should include segregation of the particles into as many categories as required to adequately describe the sample (Table III). Particles of expanded material may be segregated on the basis of particle shape, surface texture, development of a coating or "skin," vesicularity, and friability. To be distinguished from vesicular particles are those which are incompletely or not expanded. These should be separated on the basis of porosity, absorptivity, density, friability, softness, and reaction to water (softening, slaking, or swelling). The petrographic examination supplements standard tests in distinguishing clayey particles from "clay lumps" determined in accordance with ASTM Method C 142.[5] Other materials to be identified and determined quantitatively are underburned or raw material, coal, and rock particles. The content of raw material commonly can be most easily and accurately established by X-ray diffraction or differential thermal analysis.

The individual types of particles also should be analyzed petrographically to establish the presence of free magnesia or lime. These result mainly from decomposition of calcium and magnesium carbonates in the feed during firing. They may produce distress or popouts in concrete or concrete products unless the aggregate is water- or steam-cured prior to use (**18**).

Petrographic examination also assists selection of raw materials, development of manufacturing methods and equipment, and process control.

Cinders:

Cinders used as concrete aggregate are the residue from high-temperature combustion of coal and coke in industrial furnaces. Petrographic examination should determine the physical nature of the cinder particles on the basis of composition, friability, softness, particle shape, and surface texture. Especial attention should be given to identification of sulfides, sulfates, coal, and coke.

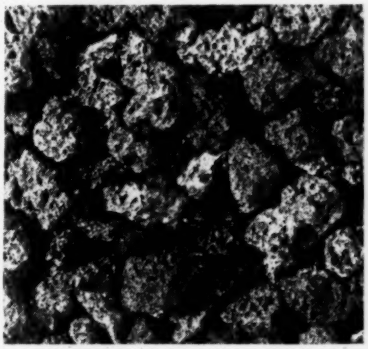

FIG. 9.—Typical Basaltic Scoria Aggregate (Natural Size) (reduced ½ in reproduction).

The pieces are black, gray, and reddish brown. Note the rounded vesicles.

Expanded Blast-furnace Slag:

Expanded blast-furnace slag is produced by carefully controlled intermingling of molten slag and water or steam in one of several ways (**11**). The petrographic examination should describe the aggregate in terms of the nature of the expanded particles, including their particle shape, surface texture, friability, or softness, and content of contaminating substances, such as dense slag.

Pumice, Scoria, Tuff, and Volcanic Cinder:

Pumice, scoria, tuff, and volcanic cinder used for lightweight aggregate are naturally-occurring porous or vesicular volcanic materials. Pumice is a very highly porous and vesicular volcanic rock composed largely of natural glass drawn into approximately parallel or loosely entwined fibers and tubes. Scoria is a highly porous and vesicular volcanic rock in which the vesicles typically are rounded or elliptical in cross-section, the interstitial glass occurring as thin films (Fig. 9). Tuff is a general term designating consolidated volcanic ash of any lithologic type or physical character. Volcanic cinder is a loose accumulation of highly vesicular (scoriaceous) fragments of lava, predominantly ranging from 4 to 32 mm in diam.

Petrographic examination of these types of aggregate includes segregation of the particles on the basis of particle shape, surface texture, porosity or vesicularity, fracturation, friability or softness, weathering, specific gravity, secondary deposits in voids, coatings, and potential alkali reactivity. Extraneous or contaminating substances are primarily dense particles of volcanic rock and organic matter. In production of lightweight aggregate, two types of volcanic materials are occasionally intermixed for economy or to control gradation or unit weight. The type and relative proportion of the materials can be established by petrographic examination.

Volcanic glass with an index of refraction less than 1.535 is potentially deleteriously reactive with cement alkalies; glass whose index is in the range 1.535 to 1.570 probably is alkali reactive. Opal, chalcedony, tridymite, and cristobalite are also common alkali reactive constituents of volcanic aggregates. However, in spite of alkali-aggregate reaction and formation of alkalic silica gel, expansion usually is prevented by the abundant voids into which the hydrating gel can escape without development of excessive stress in the mortar. For example, a very highly porous rhyolite tuff from Hideaway Park, Colo., containing abundant tridymite caused only 0.041 per cent expansion of a high-alkali cement mortar during 1 yr of moist storage in accordance with ASTM Method C 227,[10] yet the specimen contained abundant alkalic silica gel. A similar but dense tuff from near Castle Rock, Colo. produced an expansion of 0.400 per cent under the same conditions.

Perlite:

When heated rapidly to fusion, certain obsidians and pitchstones release gases which, being trapped within the molten glass, vesiculate the rock, and cause disruption into small pieces. The product is known commercially as Perlite.

Petrographic examination should indicate the composition of the aggregate in terms of particle shape, surface texture, composition, density, friability, or fragility, and potential alkali reactivity. Perlite may contain particles of dense volcanic rock or individual crystals.

Being composed of volcanic glass, typical Perlite is potentially reactive with cement alkalies, although significant expansion may not occur because of the porosity of the particles. However, laboratory tests demonstrate that certain Perlites produce significant expansion of mortar stored in accordance with Method C 227[10] in combination with either high-alkali or low-alkali cement. Such volume change will not necessarily cause structural distress if appropriately accommodated in the design.

Exfoliated Vermiculite:

Exfoliated vermiculite is produced by rapid heating of the micaceous mineral, vermiculite. Release of combined water expands the crystals—like an accordian—increasing the volume to as much as 30 times its original size. The degree of expansion varies widely, depending upon mineralogic properties and purity and the conditions of firing.

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[10] Tentative Method of Test for Potential Alkali Reactivity of Cement-Aggregate Combinations (C 227 – 52 T), 1952 Book of ASTM Standards, Part 3, p. 44.

During petrographic examination, the particles of vermiculite are segregated by degree of expansion, elasticity or brittleness of the flakes, and fragility of the expanded crystals. These differ significantly within individual samples from some sources, especially from marginal deposits where the vermiculite grades into hydrobiotite or biotite. Also to be reported is intermixture of the vermiculite with particles of rocks and minerals occurring with the vermiculite in the deposit.

Diatomite:

Crushed and sized natural diatomite typically is soft, porous, absorptive, and ranges from firm to pulverulent. Finely divided opal and opaline skeletons of diatoms are the predominant constituents. Fine sand, silt, clay, and volcanic ash are present in widely differing proportions. At least certain diatomites produce significant expansion of mortars stored in accordance with ASTM Method C 227,[10] with both high- and low-alkali cement.

NOTES ON THE PETROGRAPHY OF AGGREGATE CONSTITUENTS

Rhyolite, Dacite, Latite, Andesite, and Analogous Tuffs:

Rhyolite, dacite, latite, and andesite containing volcanic glass or submicroscopically crystalline (cryptocrystalline) phases are the most widespread cause of deleterious alkali reactivity of aggregate in western United States. Aggregate containing 3 per cent or more of such materials should be used only with low-alkali cement or with a pozzolan known to control alkali-aggregate reaction. If rocks of these types are present in excessive amount in aggregate, only small expansion might result even if high-alkali cement were used (**19, 20**). Tuffs and pumice equivalent in composition to these rocks are also potentially alkali reactive, except that the expansion exhibited by the concrete or mortar is reduced more or less by the porosity of the particles.

Potentially reactive volcanic rock almost always can be recognized with a hand lens or stereoscopic microscope. The presence of glass or cryptocrystalline phases in the groundmass is indicated by characteristic vitreous, waxy, or satiny luster. Deleterious glassy or cryptocrystalline phases occur in obsidian, pitchstone, perlite, pumice, felsite, and related porphyries. Deleterious alkali reactivity has not been demonstrated in volcanic glass whose index of refraction exceeds 1.535, but glass whose index of refraction is 1.570 or less is suspect. Microcrystalline or fine-grained rocks of analogous mineralogic and chemical composition are not deleteriously alkali reactive.

Opal, chalcedony (including the poorly defined types, such as lussatite and quartzine), tridymite, and cristobalite are common in volcanic rocks. They occur especially in fractures, in vesicles, and interspersed through the groundmass. Opal and chalcedony are common as coatings on sand and gravel containing high proportions of volcanic rocks.

These volcanic rocks are common in western United States in both sand and gravel, and occasionally are proposed for use as crushed stone aggregate. Pumicite of rhyolitic and dacitic composition is very common in fine fractions of sand in the Pacific Northwest and in the Great Plains area of central United States.

These volcanic rocks are unusually susceptible to weathering. Consequently, they should be observed carefully for presence of clay minerals, especially the expanding lattice types. For this purpose, staining tests are convenient (**21**). Rhyolites and dacites also are prone to extreme fracturation as the result of strain caused by cooling of the lava. Such fractures accelerate weathering and contribute to breakdown of the aggregate in processing and mixing.

Phonolite and Syenite:

An analcitic phonolite porphyry from Missouri Buttes near Sundance, Wyo., and an augite syenite from near Harlem, Mont., containing about 15 per cent of natrolite do not cause deleterious expansion of mortar bars containing high-alkali cement when tested in accordance with ASTM Method C 227.[10] However, supplementary tests demonstrate that the phonolite porphyry contributes significantly to alkali-aggregate reaction when finely divided (passing the No. 100 sieve) and combined with an alkali reactive aggregate (Pyrex). Therefore, rocks of these types should not be used as aggregate in combination with deleteriously alkali reactive aggregate, regardless of the alkali content of the cement, unless the combination is demonstrated to be stable by appropriate tests.

Claystone and Shale:

Many shales and claystones are unsound physically because they absorb water and swell or slake. During petrographic examination, representative pieces of shale or claystone should be immersed in water and later dried to observe the degree of water sensitivity. Many apparently stable clayey rocks disintegrate surprisingly upon wetting and drying.

Clay minerals of the montmorillonite group and some illites are especially undesirable constituents because they adsorb water into the crystal lattice and change considerably in volume with wetting and drying, producing swelling pressure exceeding the tensile strength of concrete. These types are widespread in Western United States. Members of the kaolinite group do not produce significant swelling pressure, although they usually are highly absorptive and susceptible to softening and slaking when wetted. Kaolinite clay and shale are widespread in areas which are now warm and humid or were so in the geologic past. The several types of clay minerals can be distinguished readily by X-ray diffraction or differential thermal analysis. Staining tests are a great aid to microscopy (21).

The characteristic qualities of claystone and shale lead to increased water requirement and decreased strength, durability, volume stability, and abrasion resistance of concrete. Some shales are sufficiently low in specific gravity to segregate and accumulate in near-surface concrete. Particles of claystone and shale are common causes of popouts. "Clay balls" are similar to claystone, except that they are produced by agglomeration, rolling, and molding of clay and mud transported by streams from which sand and gravel are being deposited.

Neither montmorillonite nor kaolinite is deleteriously reactive with cement alkalies. However, tests indicate that release of exchangeable sodium from montmorillonite can contribute to alkali-aggregate reaction if alkali reactive constituents are present in the aggregate. On the other hand, shale and claystone commonly contain constituents which are potentially chemically reactive in concrete. These include organic matter, sulfides (marcasite and pyrite), sulfates (gypsum and alunite-jarosite), soluble salts, or alkali reactive minerals. Opal and chalcedony are the commonest alkali reactive constituents; they are abundant in diatomaceous or siliceous shales.

Concretions:

Concretions are nodules produced in sedimentary or pyroclastic formations by local concentration of minerals deposited by ground water. Concretions typically are harder than the enclosing material, and so commonly accumulate in sand and gravel, even though the enclosing material is thoroughly decomposed and eroded. Concretions are common in shale, claystone, siltstone, tuff, loess, soil, limestone, dolomite, and sandstone. The cementing material usually is iron oxide, opal, calcium carbonate, chalcedony, or sulfides.

Ferruginous concretions released by erosion of claystone, shale, siltstone, and fine sandstone are widespread in eastern Colorado, Nebraska, Wyoming, Montana, the Dakotas, Michigan, and Minnesota. They occur in gravel and in coarse sand. They are otherwise called "clay ironstones" or "chocolate bars." The outer part of the particle is hard, but the interior usually is soft and highly porous. These concretions reduce freezing-thawing resistance of concrete, and are a common cause of popouts.

Calcareous concretions produced along root channels in soil, clay, pumicite, or loess are common constituents of coarse aggregate and coarse fractions of sand in many areas, especially in the great plains area and the Columbia Basin in Washington. Opal is a common constituent, so that these types of concretions usually are deleteriously reactive with cement alkalies. These types of concretions can be recognized by their white or light color, irregular shape, composition, high absorptivity, and tubular passageways.

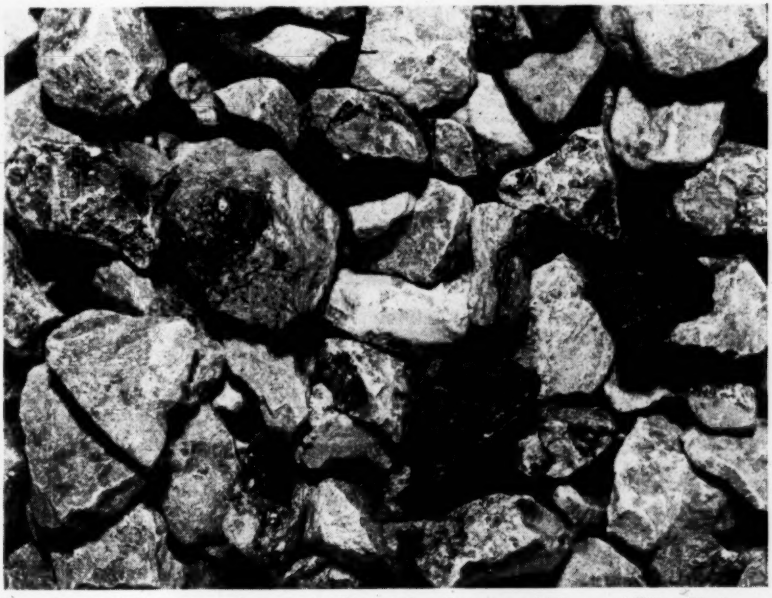

FIG. 10.—Crushed Limestone Aggregate Containing Seams and Pieces of Illite Shale at Webster Dam, Kan. (× ½).

The physical quality was indicated as follows: satisfactory, 61 per cent; fair, 34 per cent; poor, 5 per cent by weight.

Limestone, Dolomite, and Marble:

Limestone and dolomite vary widely in grain size, porosity, and content of noncalcareous constituents. Indeed, they grade imperceptibly into sandstone, siltstone, shale, and chert. Problems of nomenclature are summarized by Mather (**22**). Also, these rocks usually are interbedded with sedimentary rocks of other types; they ordinarily will appear in the finished aggregate if present in the quarry. Calcareous concretions are discussed above.

Limestone, dolomite, and marble show considerable difference in thermal coefficient of expansion in different directions if the carbonate crystals are oriented preferentially. This difference and the departure of the coefficient from that of the cement paste is considered by some (**23**) to affect durability of exposed concrete. This is an elusive property whose significance remains to be evaluated definitely.

Noncarbonate constituents greatly influence quality of limestone and dolomite aggregate. They include clay, sulfides, sulfates (gypsum and anhydrite), organic matter, and alkali reactive constituents. Clays of montmorillonite, illite, or kaolinite types occur in several ways: in uniformly dispersed form throughout the rock; enclosed within carbonate crystals; as fillings of fractures or solution channels; or in sedimentary strata or laminae (Fig. 10).

In hand specimens, the hardness, toughness, and form of fracture surfaces are clues to the degree of interlocking of carbonate minerals, presence of cryptocrystalline, microcrystalline, or amorphous silica, and the abundance and distribution of clay. A rough fracture surface indicates poor interlocking of grains, absence or paucity of silica, and probable presence of interstitial clay. An uneven or steplike fracture surface indicates presence of internal fractures or poorly bonded planes of stratification. These should be closely examined for presence of clay. A knife blade drawn across a fracture surface will reveal presence of hard noncarbonate constituents in the rock by scrapings of the metal.

Petrographic examination is aided by simple tests to determine reaction to water, such as absorption of droplets, capillary suction, softening, slaking, or swelling. If the texture of the rock permits wetting of the clay constituents, excessive volume change may occur, especially if expanding lattice clays (montmorillonite and some illites) are present. Mather (**22**) concludes that absorptive limestone containing approximately 5 per cent or more of montmorillonite clays may noticeably reduce freezing-thawing resistance of concrete.

Chert is very common in limestone and dolomite as large irregular or lenticular masses, local segregations of any size, or interstitial phases. Chalcedonic phases which appear brown or tan in thin section are more alkali reactive than the colorless phases in at least some occurrences Limestone or dolomite containing 3 per cent or more of chalcedonic chert should be regarded as potentially alkali reactive.

Chert:

Chert is a fine-grained siliceous rock composed of microcrystalline to cryptocrystalline quartz, chalcedony (or its poorly defined associates, such as quartzine, lussatite, or lutecite showing a positive elongation and an unusually low index of refraction), or opal. Chert occurs in many ways geologically and is a widespread constituent of aggregate (**24, 25**).

Opal is the most alkali reactive of all minerals. Aggregates containing as little as 0.25 per cent by weight of opal should be considered deleteriously alkali reactive. Most cherts and other rocks containing microcrystalline to cryptocrystalline quartz and chalcedony that have been tested with high-alkali cements in the laboratory have been found to cause a deleterious degree of expansion. Likewise, many of these types have been identified with alkali-aggregate reaction in field structures (**19, 20, 25**).

However, the rate and magnitude of alkali reactivity of chalcedony and microcrystalline to cryptocrystalline quartz ranges widely. No correlation has been established between potential alkali reactivity and any optical, petrographic, or chemical property, including crystallinity, index of refraction, and loss on ignition (Table VII). X-ray diffraction patterns of typical flamboyant chalcedony, such as that from Serra do Mar, Brazil, are identical with those of quartz, except that they typically fade at larger diffraction angles, corresponding to smaller *d* spacings, probably as the result of disorder in the crystal lattice. However, the highly alkali reactive novaculite from Hot Springs, Ark., produces a pattern identical with that of quartz, showing no fading in any portion.

TABLE VII.—RELATIONSHIP OF INDEX OF REFRACTION AND LOSS ON IGNITION TO ALKALI REACTIVITY OF CHERTS AND SILICA MINERALS.

Material	Index of Refraction[a]	Loss on Ignition, per cent	Mortar Expansion, per cent[b]
Opal, near Quincy, Wash.	*ca* 1.41	3.92	1.613
Opal, Virgin Valley, Nev.	1.413	3.55	2.218
Chalcedony, Serra do Mar, Brazil	1.536–1.543	0.89	0.264
Chert, Joplin, Mo.	1.546	1.40	0.214
Flint, Crown Point, N. Y.	1.546	1.70	0.352
Flint, Dover Cliffs, England	1.541	1.01	0.137
Novaculite, Hot Springs, Ark.	1.547	0.13	0.561
Quartz, Buffalo Park, Colo.	1.544–1.553	...	0.033

[a] Except for the chalcedony and quartz the indicated index of refraction is the average index measured on the microcrystalline to cryptocrystalline or amorphous matrix of the specimen. The index of refraction of the Quincy opal is highly variable.

[b] Mortar bars 1 by 1 by 10-in.; mix parts 1:2; aggregate graded 20 per cent by weight each No. 4–8, No. 8–16, No. 16–30, No. 30–50, No. 50–100; cured 7 days in fog room at 70 F, then stored at 100 F in sealed cans in accordance with Method C 227;[10] high-alkali cement (1.30 per cent Na_2O and 0.12 per cent K_2O). The indicated expansion is the maximum expansion at 1 yr obtained in a series of mortars in which the test material replaces 5 to 100 per cent by weight of pure quartz aggregate equally in all size fractions.

There is no alternative now to classifying all cherts as deleteriously alkali reactive in the petrographic report. The conclusion will be fortified if the chert observed in the sample can be correlated specifically with one or more cherts whose alkali reactivity has been established by test or service.

Cherts that are porous, fractured, and leached are susceptible to breakdown in freezing and thawing; they contribute to reduced durability of concrete and formation of popouts. In the United States, cherts of this type are important in the southeastern states as well as in Illinois, Indiana, Ohio, Missouri, and Michigan. The petrographic examination should classify cherts on the basis of composition; color; weathered rims; luster; fractures; form, size, and abundance of pores and channelways; absorptivity; and the nature and identity of void and fracture fillings.

Chat is chert aggregate produced as a by-product of the lead-zinc mining industry in the Tri-State Mining District of southeastern Kansas, southwestern Missouri, and northeastern Oklahoma (**26**). Of especial importance is the shape, angularity, and surface texture of the chert particles and the abundance of sulfides, limestone, ferruginous particles, talc, and gypsum. Weathering of sphalerite in the chats in the stock piles produces zinc carbonate (smithsonite) which retards set of concrete. The proportion of zinc carbonate in the aggregate should not exceed 0.30 per cent by weight of the cement to be used in the concrete. Chert from Joplin, Mo., similar to chert in chat aggregate is potentially deleteriously reactive with cement alkalies.

Cherts also commonly contain pyrite or marcasite whose oxidation and hydration in particles near the surface of the concrete lead to popouts and local staining.

Basalt, Diabase, and Dolerite:

Basalt, diabase, and dolerite are widespread geographically and geologically, being especially important in the Pacific Northwest, New Jersey, eastern New York and Connecticut. Basalts range from glassy to microcy.stalline. Diabases and dolerites usually range from microcrystalline to fine-grained, although glassy or cryptocrystalline interstitial phases occur in some types. The glass phase usually is low in silica, and the index of refraction characteristically exceeds 1.570. This glass is not deleteriously reactive with cement alkalies. Basalt glass is commonly altered by hydration to the gel palagonite. Palagonite is not deleteriously reactive with cement alkalies. Uncommonly, the glassy phase occurring in basalt is more acidic than the crystalline phase. A glass of this type, whose index of refraction is 1.510, has been found to be deleteriously reactive (1). The microcrystalline to cryptocrystalline interstitial phase in diabase typically is an intimate mixture of orthoclase, quartz, and magnetite. This mixture is innocuous so far as alkali reactivity is concerned.

Zeolites of several types, especially analcite, stilbite, and thomsonite are common in vesicles and the groundmass of basalt, diabase, and dolerite. These are not deleteriously alkali reactive. However, they may release alkalies by cation exchange reaction with the calcic solutions permeating concrete, and thus augment alkali-aggregate reaction if susceptible aggregate constituents are present.

Basalt, diabase, and dolerite almost always contain nontronite, the iron-bearing member of the montmorillonite group, as an alteration product of the volcanic glass, palagonite, ferromagnesian minerals, or plagioclase. When nontronite constitutes more than 25 per cent by volume of the rock, extensive volume change with wetting-drying and reduced freezing-thawing resistance of concrete should be anticipated. The presence of nontronite in moderate to excessive proportion is indicated by light green or brown powder on pieces of crushed stone. Also, decreased abrasion resistance causes rounding of edges and corners of the stone during processing.

Deposits of sand and gravel containing a high proportion of glassy or palagonitic basalt commonly contain zones coated by opal or mixtures of opal and calcium carbonate.

Granite, Monzonite, and Pegmatite:

Granite, monzonite, and pegmatite are typically coarse-grained and are composed predominantly of quartz and the potassium feldspars, orthoclase and microcline. Pegmatites commonly are composed of crystals which are several inches across. Characteristically, the crystals are poorly interlocked so that, with slight weathering and abrasion, these rocks disintegrate to their granular components. In certain areas, such as the plains east of the Rocky Mountains, the gravel and sand are composed largely of quartz and potassium feldspar. Pebbles in gravel retained on the $\frac{3}{4}$-in. sieve commonly are individual crystals of microcline. Orthoclase and microcline typically constitute 33 to 50 per cent by weight of sand along the Republican and Platte Rivers.

In Kansas, Nebraska, Oklahoma, and parts of Iowa and Missouri, these aggregates are associated with rapid deterioration of concrete. The distress is associated with either low- or high-alkali cement. The mechanism of the expansion and cracking is not known. Alkali reactive rhyolite, tuff, limestone, and chert are commonly present and undoubtedly participate in alkali-aggregate reaction when combined with high-alkali cement. The deleterious aggregates can be recognized petrographically by their high content of granite, pegmatite, and individual crystals of potassium feldspar. The distress is thought to be related to thermal properties, poor bond with cement, and rigidity of the particles of feldspar, coarse-grained granite, and pegmatite.

Granite, monzonite, and pegmatite are susceptible to granulation by weathering and alteration to kaolinite or montmorillonite-type clays. Opal produced by weathering can cause slight alkali reactivity (27). Pyrite or secondary sulfates are sometimes introduced by solutions during geologic time.

Gabbro, Anorthosite, Diorite, Granodiorite, and Dunite:

Gabbro, anorthosite, diorite, and granodiorite are similar in texture to granite, but the constituent crystals typically are better interlocked. Moreover, the predominant feldspar is plagioclase rather than potassium feldspar. These rocks typically are tougher and more resistant to granulation than granite. Ferromagnesian minerals include hornblende, pyroxene, and biotite. Biotite (sometimes altered to hydrobiotite) is abundant in some sands as a result of release from granitic or granodioritic rocks. Dunite is granular in texture and is composed essentially of olivine.

Gabbros are especially susceptible to alteration because of the abundance of ferromagnesian minerals and the calcium-rich composition of the plagioclase. However, no regional difficulties, such as are related to granite and pegmatite, are known to be associated with gabbro, anorthosite, diorite, granodiorite, or dunite.

Gabbro, anorthosite, diorite, granodiorite, and dunite are not alkali reactive. Search should be made for zeolites resulting from alteration of the basic plagioclase.

Sandstone, Quartzite, and Graywacke:

Sandstone and graywacke vary widely in strength, elasticity, porosity, and composition because of difference in abundance and identity of the intergranular binding agents. These rocks range from satisfactory to poor in physical quality, depending upon particle shape, surface texture, porosity, fracturation, friability, and softness. Occasionally, sandstones are cemented by chalcedony, cryptocrystalline to microcrystalline quartz, or opal. These are potentially deleteriously reactive with cement alkalies. Opaline sandstones are widespread in the Ogallala formation in western Nebraska, Kansas, Oklahoma, Texas, and the adjacent parts of the states to the west.

Quartzites are quartzose sandstones cemented by interstitial quartz deposited in crystallographic continuity with the grains. Pebbles of quartzite usually are smooth and impervious. Crushed particles of quartzite typically are harsh and chiplike.

Graywacke is commonly interbedded with shale, chert, and siltstone in the geologic formation, and the particles of these rocks frequently are present in gravels and coarse sands containing graywacke. The matrix in graywacke is clayey, micaceous, and silty. Water sensitivity of the matrix should be determined by simple tests. Typical graywacke is not deleteriously alkali reactive. However, individual types should be closely examined for potentially reactive constituents.

Gneiss and Schist:

Gneiss and schist are variable in composition, structure, and physical properties. They commonly contribute flat or elongated particles to aggregate, but particles of some gneisses and schists approach the equidimensional. With hydrothermal action, sulfides or sulfates may be introduced. Weathering develops friability, softness, and fracturation. No gneisses and schists are known to be alkali reactive.

Serpentine:

Serpentine is a rock composed essentially of the hydrated magnesium silicate, antigorite. The texture is variable, ranging from granular to schistose. Particles in aggregate should be segregated in accordance with established criteria, especially fracturation, presence of sulfides, softness, talcose surface texture, particle shape, and presence of alkali-reactive constituents. Some serpentines are partially silicified and contain chalcedony or cryptocrystalline quartz. Rocks of this type have been found to be deleteriously reactive with cement alkalies.

Slate and Phyllite:

Slate and phyllite usually produce flat or elongated pieces. Fracturation is frequent. In three structures, phyllite is known to have caused significant distress as the result of alkali-aggregate reaction in concrete. The active constituent apparently is microcrystalline to cryptocrystalline quartz.

A red slate containing segregations of chalcedony and cryptocrystalline quartz has been found to be deleteriously alkali reactive by the quick chemical test (Method C 289[11]) and this is corroborated by a mortar test similar to Method C 227.[10]

Quartz:

Individual particles of coarsely crystalline quartz are the predominant constituent of the fine fraction of most natural sand. They are common in most coarse sand and gravel, and in the fine aggregate produced by crushing quartzose rock. If abundant, such particles may reduce strength and resistance to weathering of the concrete (**28**), probably because of their smooth surface texture, rigidity, and relative impermeability. Microcrystalline and cryptocrystalline forms of quartz have been discussed in the section on chert.

Coarsely crystalline quartz normally is innocuous with respect to alkali-aggregate reaction. However, examination of concrete containing certain highly quartzose sands and gravels from parts of Long Island, N. Y., and parts of northern New Jersey, indicates that coarsely crystalline quartz that is internally intensely fractured, granulated, and strained or filled by microscopical or submicroscopical inclusions can contribute significantly to alkali-aggregate reaction. Illite is common as inclusions in this type of quartz. The potentially deleteriously reactive quartz particles typically are white or milky; however, not all white or milky quartz is deleterously alkali reactive. Additional studies of these phenomena are required to establish specifically the nature of the quartz and the conditions under which the effects of the reaction become significant.

Feldspars:

Potassium feldspars and plagioclase feldspars are innocuous so far as alkali reactivity is concerned. However, both are susceptible to weathering and the accompanying development of fracturation and production of clay minerals. Moreover, the thermal coefficient of expansion of the common potassium feldspars, orthoclase and microcline, is sufficiently low (0.0×10^{-6} to 0.6×10^{-6} per deg Fahr) in one crystallographic direction to be considered a contributing cause of distress in concrete subjected to heating-cooling and wetting-drying if the aggregate is highly feldspathic. Large expansion can be produced in concrete beams containing only potassium feldspar as aggregate by heating and drying followed by immersion in water at a constant temperature (**28**). Experience with feldspathic and granitic aggregates in the great plains area is noted above.

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[11] Tentative Method of Test for Potential Reactivity of Aggregates (Chemical Method) (C 289 – 52 T), 1952 Book of ASTM Standards, Part 3, p. 943.

In weathered aggregate, the feldspars are altered to kaolinite or montmorillonite-type clays, less commonly to zeolites, and consequently are fair to poor in quality. Incipient alteration is indicated by opening of cleavage planes. Particles so affected can be broken easily with a dissecting needle.

Zeolites:

Analcite, stilbite, and laumontite (and leonhardite) are not deleteriously reactive with cement alkalies. Heulandite has been reported to be deleteriously alkali reactive (**1**), but review of the data indicates that the conclusion should be regarded as highly tentative until corroborated by additional tests. Natrolite has been reported to be alkali reactive. However, an augite syenite containing about 15 per cent by volume of natrolite did not produce deleterious expansion of mortar when combined with high-alkali cement in a procedure similar to Method C 227.[10]

By cation-exchange reactions, zeolites can supply alkalies to mortar and thus contribute to alkali-aggregate reaction if alkali reactive constituents are present. Also, calcic zeolites, such as Ca-leonhardite, apparently take up sodium from high soda mortar and thus reduce alkali-aggregate reaction.

Loughlin (**29**) concluded that reversible transformation of leonhardite to laumontite in weathered anorthosite used as aggregate caused disintegration of cast stone and stucco in the Los Angeles area several decades ago.

Micas:

Micas in aggregate mainly are biotite and muscovite; the altered forms, such as hydrobiotite, are common in some areas. The proportion of free mica should be determined during the petrographic examination because a limit on maximum permissible mica content is included in most specifications on concrete aggregate. The report should indicate the condition of the mica particles in terms of size, form, elasticity, softness, and mineralogic identity. The hydrous, degenerated micas can be identified by X-ray diffraction or thermal analysis. Hydrobiotite and vermiculite can be distinguished readily from biotite by their exfoliation in 30 per cent hydrogen peroxide solution.

Micas are generally thought to reduce strength and durability of concrete. Published data on these relationships are meager (**30**). Additional work would be justified.

Tridymite and Cristobalite:

The silica minerals tridymite and cristobalite are common constituents of rhyolites, dacite, and andesite, and their related tuffs. These minerals are minor or major constituents of synthetic aggregates, such as slag and silica brick. Tridymite produces great expansion of high-alkali mortar in a procedure similar to Method C 227[10] (**31**). Cristobalite is reported to be deleteriously alkali reactive (**32**).

Artificial Siliceous Glasses:

Pyrex produces rapid and great expansion of high-alkali mortars tested in accordance with Method C 227.[10] When tested by the Bureau of Reclamation in accordance with Method C 227,[10] two siliceous glasses produced excessive expansion of mortars containing either high- or low-alkali cement (Table VIII). Supplementary tests demonstrated that these glasses released large amounts of sodium in the presence of calcium hydroxide. Apparently, in the presence of hydrating portland cement, these glasses were in part converted into alkali-silica combinations capable of absorbing water and swelling.

TABLE VIII.—EXPANSION OF MORTARS CONTAINING SYNTHETIC AGGREGATES INCLUDING ARTIFICIAL GLASS.

Age, months	Linear expansion of mortar, per cent[a]			
	Aggregate Containing "opal" glass, No. M-549[b]		Aggregate Containing Soft Glass, No. M-612[b]	
	High-Alkali Cement, No. 3562[c]	Low-Alkali Cement, No. 2735[c]	High-Alkali Cement, No. 3562[c]	Low-Alkali Cement, No. 2735[c]
1......	0.056	−0.009	0.116	0.012
6......	0.482	0.049	0.532	0.324
12......	0.751	0.246	0.877	0.819
18......	0.953	0.511	1.142	1.154
24......	1.105	0.750	...	...

[a] 1 by 1 by 10-in. mortar bars; mix parts 1:2 by weight; water-cement ratio 0.40 by weight; cured 24 hr at 70 F in moist cabinet; then stored at 100 F in sealed cans in accordance with Method C 227.[10]

[b] The aggregates are a mixture of rock and mineral particles and glass. Sample No. M-549 contains about 20 per cent by weight of glass whose n = 1.485 and composition is 68.01 per cent SiO_2, 13.34 per cent Na_2O, and 1.66 per cent K_2O. Sample No. M-612 contains about 20 per cent by weight of glass whose n = 1.510 and composition is 71.99 per cent SiO_2, 15.23 per cent Na_2O, and 0.21 per cent K_2O.

[c] Cement No. 3562: type II; 1.20 per cent Na_2O; 0.04 per cent K_2O. Cement No. 2735: type II; 0.04 per cent Na_2O; 0.14 per cent K_2O.

Sulfides and Sulfates:

Sulfides and sulfates are likely to occur in aggregates composed of sand, gravel, crushed stone, or any of many processed or synthetic materials. Their presence should be expected, especially in carbonaceous sedimentary rocks or concretions, and in any rock showing evidence of hydrothermal alteration. The most widespread sulfides are pyrite and marcasite (FeS_2); pyrrhotite (FeS) is less common. Sulfides of calcium, ferrous iron, or manganous manganese should be looked for in slags. Sulfides of copper, lead, or zinc may be present in small amounts with pyrite or pyrrhotite in aggregate produced from mine wastes.

Gypsum ($CaSO_4 \cdot 2H_2O$) is the most common sulfate in aggregates, especially in some dolomites and shales. It is a frequent constituent of coatings on sand and gravel in western United States. Alunite ($K_2Al_6(OH)_{12}(SO_4)_4$) and jarosite ($K_2Fe_6(OH)_{12}(SO_4)_4$) are rare. Alunite produces great expansion of moist-stored mortars, regardless of the alkali content of the cement, and jarosite probably will react similarly. Expansion exceeded 1 per cent linearly at 1 yr when alunite constituted 5 per cent by weight of the aggregate, the minimum included in the tests. These minerals may very well occur in any hydrothermally altered rock. Jarosite commonly is revealed by iron oxide stains in voids and fractures and by intense leaching of the host rock.

Tests on barite ($BaSO_4$) have revealed no deleterious chemical reaction in portland cement concrete.

Free-Lime and Magnesia:

Free-lime (CaO) magnesia (MgO) are common constituents of refractories and synthetic aggregates produced from raw materials containing carbonates of calcium and/or magnesium. They are of concern in aggregates composed of sand, gravel, or stone only if contaminated by industrial products or wastes. Magnesia also is a constituent of some air-cooled slags. Destructive volume increase accompanies hydration and carbonation of the crystals in place (**5**). These oxides may be detected microscopically in thin sections or in polished and etched surfaces or by X-ray diffraction.

CONCLUSION

Petrographic examination should be included in the investigation and testing of concrete aggregate for use in permanent construction. Applied in the field, the method aids exploration and sampling and permits preliminary evaluation of materials from alternative sources. Detailed examination of aggregate in the laboratory supplements the standard acceptance tests, especially by: (1) detecting adverse properties; (2) comparing the aggregate with aggregates for which service records or previous tests are available; (3) explaining results of tests and justifying special tests as required; (4) detecting contamination; and (5) determining the efficiency and relative merit of processing and manufacturing methods.

Validity of the results depends upon the training and experience of the petrographer. However, with proper training and the adoption of uniform techniques and nomenclature, subjective elements in the examination are not significant.

The methods can be applied effectively to sand, gravel, crushed stone, slag, and natural or synthetic lightweight aggregate.

REFERENCES

(**1**) R. C. Mielenz and L. P. Witte, "Tests Used by the Bureau of Reclamation for Identifying Reactive Concrete Aggregates," *Proceedings*, Am. Soc. Testing Mats., Vol. 48, p. 1071 (1948).

(**2**) Katharine Mather and Bryant Mather, "Method of Petrographic Examination of Aggregates for Concrete," *Proceedings*, Am. Soc. Testing Mats., Vol. 50, p. 1288 (1950).

(**3**) R. C. Mielenz, "Petrographic Examination of Concrete Aggregates," *Bulletin*, Geol. Soc. Am., Vol. 57, p. 309 (1946).

(**4**) Roger Rhoades and R. C. Mielenz, "Petrography of Concrete Aggregates," *Proceedings*, Am. Concrete Inst., Vol. 42, p. 581 (1946).

(**5**) Roger Rhoades and R. C. Mielenz, "Petrographic and Mineralogic Characteristics of Aggregates," Symposium on Mineral Aggregates, Am. Soc. Testing Mats., p. 20 (1948). (Issued as separate publication, *ASTM STP No. 38*.)

(**6**) E. P. Rexford, "Some Factors in the Selection and Testing of Concrete Aggregates for Large Structures," *Transactions*, Am. Inst. Mining and Metallurgical Engr., Vol. 187, No. 3, p. 395 (1950).

(**7**) Bureau of Reclamation, "Concrete Manual," U.S. Dept. Interior, 5th Ed. (1949).

(**8**) A. T. Goldbeck, "The Nature and Effects of Surface Coatings on Coarse Aggregates," *Proceedings*, Highway Research Board, Vol. 12, Part I, p. 305 (1933).

(**9**) W. Y. Holland and R. H. Cook, "Alkali Reactivity of Natural Aggregates in Western United States," *Mining Engineering*, p. 991 (1953).

(**10**) G. F. Loughlin, "Usefulness of Petrology in the Selection of Limestone," *Rock Products*, Vol. 31, March 17, 1928, p. 50.

(**11**) G. W. Josephson, F. Sillers, Jr., and D. G. Runner, "Iron Blast Furnace Slag: Production, Processing, Properties, and Uses," Bureau of Mines, U.S. Dept. Interior, *Bulletin No. 479* (1949).

(**12**) G. R. Rigby, "The Thin Section Mineralogy of Ceramic Materials," The British Ceramic Research Assoc., 2nd Ed. (1953).

(**13**) R. W. Nurse and H. G. Midgley, "The Mineralogy of Blast Furnace Slag," *Silicates Industriels*, Vol. 16, No. 7, p. 211 (1951).

(**14**) R. B. Snow, "Identification of $CaO \cdot MgO$ Orthosilicate Crystals, Including Merwinite ($3CaO \cdot MgO \cdot 2SiO_2$), Through the Use of Etched Polished Sections," Am. Inst. Mining and Metallurgical Engr., *Technical Publications No. 2167*, (1947).

(**15**) R. B. Snow, "Examination of Refractory Specimens in Reflected Light," *Journal*, Am. Ceramic Soc., Vol. 36, No. 9, p. 299 (1953).

(16) T. W. Parker and J. F. Ryder, "Investigations on 'Falling' Blast Furnace Slags," *Journal*, Iron and Steel Inst., Vol. 146, No. II, p. 21 (1942).

(17) R. S. McCaffery, J. F. Oesterle, and Leo Schapiro, "Composition of Iron Blast Furnace Slag," Am. Inst. Mining and Metallurgical Engr., *Technical Publication No. 19* (1927).

(18) Bror Nordberg, "The Basalt Rock Company Story," *Rock Products*, Vol. 57, p. 104 (1954).

(19) Duncan McConnell, R. C. Mielenz, W. Y. Holland, and K. T. Greene, "Cement-Aggregate Reaction in Concrete," *Proceedings*, Am. Concrete Inst., Vol. 44, p. 93 (1948).

(20) Duncan McConnell, R. C. Mielenz, W. Y. Holland, and K. T. Greene, "Petrology of Concrete Affected by Cement-Aggregate Reaction," *Engineering Geology* (*Berkey*) *Volume*, Geol. Soc. Am., p. 225 (1950).

(21) R. C. Mielenz and M. E. King, "Identification of Clay Minerals by Staining Tests," *Proceedings*, Am. Soc. Testing Mats. Vol. 51, p. 1213 (1951).

(22) Katharine Mather, "Crushed Limestone Aggregates for Concrete," *Mining Engineering*, Vol. 10, No. 5, p. 1022 (1953).

(23) E. J. Callan, "Thermal Expansion of Aggregates and Concrete Durability," *Proceedings*, Am. Concrete Inst., Vol. 48, p. 485 (1952).

(24) C. E. Wuerpel and E. P. Rexford, 'The Soundness of Chert as Measured by Bulk Specific Gravity and Absorption," *Proceedings*, Am. Soc. Testing Mats., Vol. 40, p. 1021 (1940).

(25) Bryant Mather, "Cracking of Concrete in the Tuscaloosa Lock," *Proceedings*, Highway Research Board, Vol. 31, p. 218 (1952).

(26) R. L. Peyton, "An Investigation of Crushed Flint Aggregates in Portland Cement Concrete," The State Highway Commission of Kansas, *Research Project No. 8001* (mimeographed) (1945).

(27) A. R. Alderman, "Studies in Cement-Aggregate Reaction: Part I, Australian Aggregates and Cements," Australia Council for Scientific and Industrial Research, *Bulletin No. 229*, p. 7 (1947).

(28) E. C. Higginson and D. G. Kretsinger, "Prediction of Concrete Durability from Thermal Tests of Aggregate," *Proceedings*, Am. Soc. Testing Mats., Vol. 53, p. 991 (1953).

(29) G. F. Loughlin, "An Interesting Case of Dangerous Aggregate," *Proceedings*, Am. Concrete Inst., Vol. 19, p. 142 (1923).

(30) W. N. Willis, "Tests to Determine the Effect of Mica on the Strength of Concrete," *Engr. News*, Vol. 59, p. 145 (1908).

(31) F. B. Hornibrook, H. Insley, and L. Schuman, "Notes on the Effect of Alkalies in Portland Cement on the Durability of Concrete,'" *Proceedings*, Am. Soc. Testing Mats., Vol. 43, p. 218 (1943).

(32) A. R. Alderman, Principal Research Officer, Division of Industrial Chemistry, Council for Scientific and Industrial Research, Australia. *Personal communication*.

(33) Am. Concrete Inst. Committee 201, Report on Blast Furnace Slag as Concrete Aggregate, *Proceedings*, Am. Concrete Inst., Vol. 27, pp. 183, 661 (1930–31).

MASONRY CRACKING AND DAMAGE CAUSED BY MOISTURE EXPANSION OF STRUCTURAL CLAY TILE*

By J. W. McBurney[1]

Synopsis

The present paper describes several cases of damage in masonry built in part with structural clay tile. From laboratory tests of the various masonry materials together with consideration of various other possible causes, moisture expansion of the structural clay tile was established as the cause of the damage. Methods of test for existing moisture expansion and for possible future expansion are described in detail. This is the second in a series of papers reporting somewhat unusual causes of cracking of masonry associated with expansion.

In a previous paper (**1**),[2] the author considered cracking of masonry caused by expansion of mortar containing free magnesium oxide (MgO). The present paper reports the results of studies, including laboratory examinations, of certain cases of cracking in which the evidence indicates that the damage was caused by moisture expansion of structural clay tile.

Review of Literature

Schurecht and Pole (**2**) in 1929 first used the term "moisture expansion" in connection with ceramic bodies. These authors, referring to an earlier paper by Schurecht (**3**), stated "It has been shown that a type of delayed crazing found on glazed ceramic ware may, in certain cases, be caused by a gradual expansion of the body during exposure or was produced by the action of moisture while the glaze generally does not expand in the same manner. This type of expansion may be called 'moisture expansion' to distinguish it from other types. It has furthermore been shown that expansions of ceramic bodies similar in magnitude to those obtained during long periods of storage may be produced by subjecting them to steam at a pressure of 150 psi for one hour in an autoclave." Schurecht's 1928 paper (**3**) is also noteworthy for presenting a method for estimating the amount of expansion that had resulted from previous exposure. Mills (**4**) and Treischel (**5**) presented the results of studies of the effect of variations in the time of exposure and pressure in autoclaving. The latter author used pressures up to 250 psi and periods of exposure up to 7 hr. He reported that increase in pressure increased expansion for equal times of exposure but the percentage increase depended upon the

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[2] The boldface numbers in parenthesis refer to the list of references appended to this paper, see p. 1238.

nature of the specimen. For example, "the high-expansion body shows about 70 per cent increase in expansion for each 100 per cent increase in pressure while the low-expansion body shows about 55 per cent increase in expansion for the same 100 per cent pressure increase." He also obtained greater expansions for cumulative (repeated) autoclavings than for a single autoclaving for the same total time of exposure.

Holscher (6) further studied the effect of some modifications of the Schurecht autoclave test and also reported that small expansions resulted from heating his specimens with carbon tetrachloride, paraffin, xylene, kerosine, or petrolatum.

Geller and Creamer (7) tested commercial whiteware (dinner plates) and experimental bodies by the methods of Schurecht (3) including measurement of length changes both from autoclaving and from heating to various temperatures. The same authors (8) confirmed the assumptions of Schurecht and in 1941 (9) reported moisture expansions also by Schurecht's methods on samples of wall tile and tableware which had been "in service or in storage for periods of time ranging from 23 years to less than 1 year."

Hill (10) reported the increase in diameter of test pieces fired at temperatures of from 500 C to 1050 C when rehydrated by exposure to saturated steam at 200 C for periods up to 96 hr. His materials included kaolinite from several sources, illite and montmorillonite. He concluded that "kaolinite, illite and montmorillonite fired at 900 C and less may rehydrate to form the clay mineral. Although the rate of rehydration may be slow under natural conditions, the expansion and possible softening of the body due to partial rehydration may cause trouble in underfired bricks containing kaolinite and illite."

Bullin and Green (11) in a recent paper reported the moisture expansion of glazed wall tiles resulting from autoclaving in saturated steam at 40 psi for periods up to 2000 hr. Moisture expansions up to 0.35 per cent under these conditions were obtained on tiles having porosities of 18 to 25 per cent. The same authors presented some data on shrinkage of previously autoclaved specimens when heated to various temperatures. Koenig (12) tabulated the modifications in the Schurecht autoclave test with respect to steam pressure and duration of exposure as used by various investigators. Koenig's paper also presented an extensive bibliography. The majority of the papers in this bibliography deal with the effect of autoclaving in causing crazing of glazes on bodies of various compositions. The autoclave test for crazing prescribed in ASTM Specification C 126 – 52 T[3] is in conformity with Koenig's (12) recommendations (1 hr at 150 psi). With the exception of Hill's paper, the literature on moisture expansion and its identification by heating and autoclaving is restricted, as far as known to the author, to the behavior of the units as related to the crazing of the glaze. The possible effect of moisture expansion in causing movement and the cracking of masonry resulting therefrom has apparently not been discussed in the literature.

PREPARATION OF SPECIMENS AND METHODS OF TEST

Schurecht's methods (3) provided measures both of the amount of expansion that had previously taken place (decrease in length resulting from heating) and of potential future expansion (increase in length resulting from autoclaving). His measurements of length changes were made by using an interferometer method (13). As far as is known to this author, the first demonstration of moisture expansion on a structural clay tile was made by use of the techniques and apparatus described by Schurecht. For reasons subsequently presented (see discussion), the apparatus and techniques herein described were substituted for those of Schurecht.

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[3] Tentative Specifications for Ceramic Glazed Structural Clay Facing Tile, Facing Brick, and Solid Masonry Units (C 126 – 52), 1952 Book of ASTM Standards, Part 3, p. 446.

Preparation of Test Specimens:

As far as permitted by the dimensions of the tile, test specimens ("prisms") in the form of rectangular parallelepipeds 10 in. in length and approximately 1 by 1 in. in cross-section were cut. The prisms were formed by cutting with a Rimlock diamond edge rotary blade using water as a coolant and lubricant except for the initial specimens. Cutting specimens without using water proved impracticable (see discussion). After forming, the ends of the prisms were drilled with a $\frac{1}{8}$-in. tungsten-carbide-tipped drill, and Parker-Kalon $\frac{1}{8}$-in. drive screws were inserted. It was found advisable to use a wooden jig to hold the test specimen during drilling. After insertion of the drive screws, the specimens were allowed to dry for 48 hr in a constant temperature room at 23 ± 3 C (73.4 ± 5.4 F). The over-all length of the prism was measured to the nearest 0.03 in. with a steel scale. The specimen was then placed in a horizontal comparator for the determination of the "as-received" length.

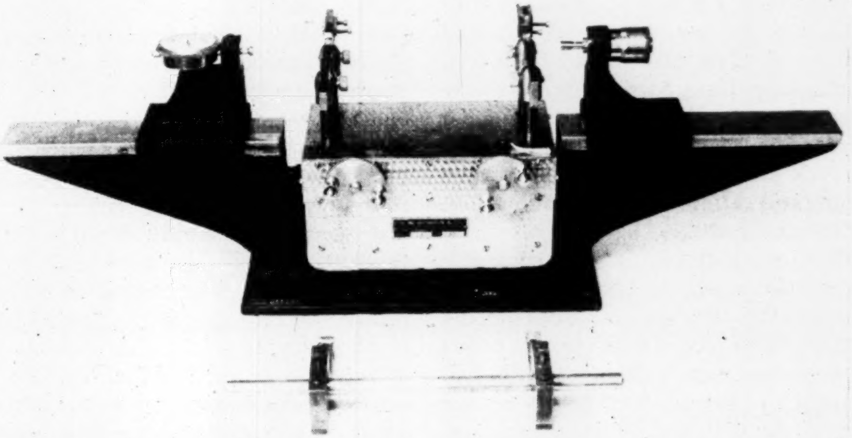

Fig. 1.—Comparator Used in Measuring Changes in Length of Specimens Cut from Structural Clay Tile and Subjected to Autoclaving and Heating. Note standard bar shown below comparator.

Measuring Apparatus (Comparator) and Methods of Measurement:

The horizontal comparator (see Fig. 1) used in this work was provided with a heavy anvil base mounted on a table top and was maintained in a constant temperature room as previously specified. On one side of the anvil, placed on a horizontally moveable block, was a calibrated micrometer dial reading to 0.0001 in. Directly opposite on a similar block was a micrometer screw, reading to 0.0001 in. Adjustment of these blocks would accommodate specimens of from 8 to 20 in. in length. If necessary, prisms less than 8 in. in length may be used. For shorter lengths, metal spacers were inserted in the comparator. The specimen was supported between the dial and the micrometer screw by two transverse bars whose level could be adjusted with two pairs of adjusting screws. One of these transverse bars was rigidly attached to its adjusting screws, while the other formed a rocker to accommodate specimens having rough or warped surfaces. A glass plate could be placed on the supporting bars to facilitate the positioning of the test specimens. A standard bar made of mild steel was used to check and calibrate the comparators before and after making readings on specimens.

After conditioning in the constant-temperature room, the test specimen was placed on the cross bars, and adjustments were made so that its spherically ended drive screws were in contact with and centered on the contact points of the stem of the dial and of the micrometer screw. The micrometer screw was then turned until a predetermined arbitrary reading was reached on the dial. This ensured that the specimen always made the same contact with the dial gage and was in the same position at each time of measurement. All subsequent determinations of length were made from readings of the micrometer screw.

Although readings were made and recorded to 0.0001 in., an accuracy and reproducibility of ±0.002 per cent on a 10-in. test specimen required closer control of temperature for successive readings than was given by ±3 C, the limits for the temperature control for the constant temperature room. Assuming a coefficient of thermal expansion of 0.000006 in. per in. per deg Cent for a shale body, a difference of 6 C would cause a change of 0.000036 or 0.0036 per cent. In order to obtain an accuracy of ±0.002 per cent, it appears necessary therefore that measurements made subsequent to the determination of the "as-received" length be made at temperatures within ±1 C of the temperatures recorded at the time of that measurement.

Heating Test:

On the assumption (*a*) that clay bodies had their least size after cooling from their original firing in the kiln, (*b*) that moisture expansion was the result of hydration of certain constituents of the clay body, and (*c*) that reheating would recover or approach the original dimensions of the body, the shrinkage (decrease in length) of the test specimen resulting from reheating to 400 C (752 F) compared with the as-received length was considered to be a measure of the expansion that had taken place during exposure. Except for bodies of very low porosity which had been in contact with water or saturated soil for a long period of time, the heating procedure hereinafter described was satisfactory. The test specimens after measurement of the as-received length were dried for not less than 18 hr in an oven maintained at a temperature between 110 and 115 C. The specimen was supported in the oven on "chairs" or other suitable supports which permitted an unrestricted change in length. The purpose of this preheating was to dry the specimens and thus avoid the possibility of spalling or disruption from the subsequent rapid heating to 400 C. The practice was to cool the specimen after preheating and to remeasure according to the method prescribed for the determination of the as-received length. Available data indicate that this remeasurement after cooling was unnecessary.

The specimen after preheating was

placed in a cold muffle furnace and was supported as before. The furnace was brought up to a temperature of 400 C (752 F) at a rate of 200 C per hr and was held at 400 C for 1 hr. The furnace was then shut off and allowed to cool overnight. The specimen was then removed to the constant-temperature room next morning and measured after at least 4 hr conditioning. The length of the specimen after furnace treatment was assumed to be the same as the length after firing in the kiln. If moisture expansion has taken place, this length will be less than the as-received length. In the absence of a significant difference, the occurrence of moisture expansion had not been established.

Since available data indicate that the order of making this heating test and the autoclave test hereinafter described had little effect on the results, the order was optional.

Autoclave Test:

The specimen was submerged in water at room temperature for 24 hr and then autoclaved according to the method prescribed in Section 5 of ASTM Method C 151 - 52.[4] After cooling in water to 23 C as prescribed in ASTM Method C 151 - 52, the specimen was surface dried with a damp cloth and then remeasured. Since the moist specimen may act as a wet bulb with consequent lowering of temperature, it is advisable to make the measurement of the saturated specimen in still air as soon as possible after removal from the water bath. Since the comparison was with the dry specimen, the correction provided in C151 by making measurements both before and after autoclaving on a saturated specimen was not applicable.

Computations:

The after-furnace-treatment reading was subtracted from the as-received reading of the micrometer screw, and the difference, if positive, was taken as the moisture expansion of the body which resulted from exposure and was calculated as a percentage of the length of the specimen. If the difference between the two readings was less than 0.002 per cent or if the after-furnace-treatment reading exceeded the as-received reading, moisture expansion was not established.

The as-received reading was correspondingly subtracted from the after-autoclaving reading, and the increase, if any, calculated as the percentage of the length of the specimen, was given as a measure of the possible future expansion above the as-received condition. The same criteria for significance of readings set for the difference between the as-received and after-furnace-treatment measurement, applied to the difference between the as-received and after-autoclaving readings. The difference between the after-furnace-treatment and after-autoclaving readings expressed as a percentage of the total length was given as a measure of the total possible expansion from the kiln-fired condition.

It should be remarked that the precautions prescribed for temperature control in the above methods are unnecessary if an accuracy of ±0.01 per cent is sufficient. Furthermore, comparators or measuring instruments of quite different types and designs could be substituted for the instrument used.

OBSERVATIONS AND MEASUREMENTS

The following three examples of damaging expansion of masonry structures caused by moisture expansion of structural clay tile are from the files of the National Bureau of Standards.

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[4] Standard Method of Test for Autoclave Expansion of Portland Cement (C 151 - 52), 1952 Book of ASTM Standards, Part 3, p. 52.

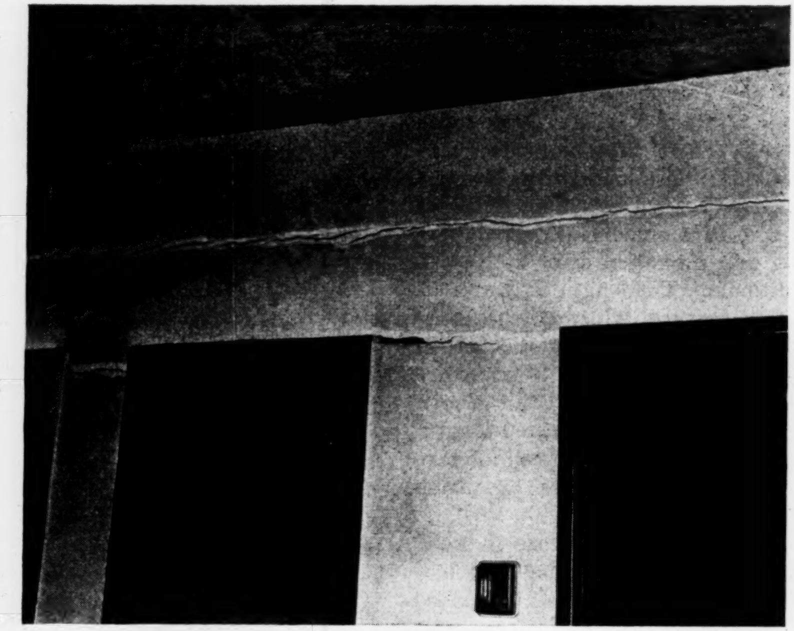

FIG. 2.—Cracking of Plastered Tile Partition in Virginia State Library. Note horizontal crack in line with top of metal doors and horizontal crack below ceiling.

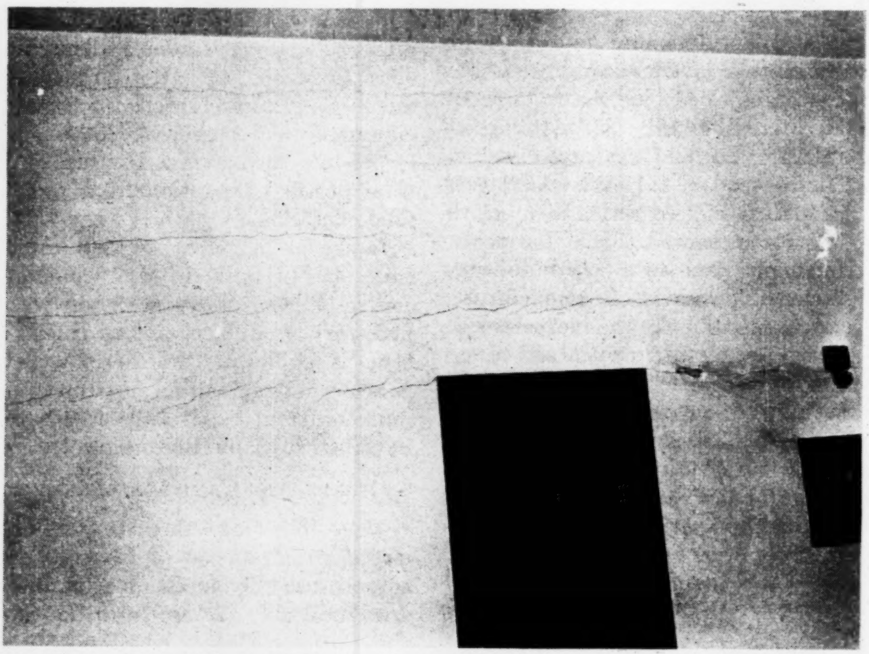

FIG. 3.—Cracking of Plastered Tile Partition in Virginia State Library. Note diagonal shearing cracks.

Virginia State Library in Richmond, Va.:

This building was reported to be about 8 years old when examined in May, 1948. The structure, which also houses the State Law Library and the Virginia Supreme Court, is of a monumental type with structural steel frame, reinforced concrete floors, and stone exterior. The building has four stories above grade, a basement and subbasement, and was designed to carry two additional stories. Nearly all of the interior partitions were of 4-in. thickness, built of fireclay tile laid on end and plastered. Tile of the same composition was used as furring on concrete walls in the basement. The public rooms and library stack rooms were air conditioned. Extensive and continuous cracking of the plaster on tile partitions was observed.

The architect had retained James M. Gongwer of Washington, D. C., as a structural consultant for the purpose of establishing the cause of the cracking. According to report this cracking started at an early age and continued uniformly thereafter. Studies made by Mr. Gongwer, including strain gage readings, demonstrated conclusively that the structural frame and concrete floors were stable and that movement was limited to the tile partitions. The most frequently observed pattern of cracking noted in 1948 consisted of two large horizontal cracks as shown in Fig. 2. It will be noted that the lower crack lines up with the top of the metal doors and that the upper crack is about 2 ft below the ceiling. The upper crack shows some tendency for formation of secondary cracks at acute angles to the main crack. Recracking of earlier pointing is noticeable. The presence of shear as shown by subsidiary cracking at an angle to the

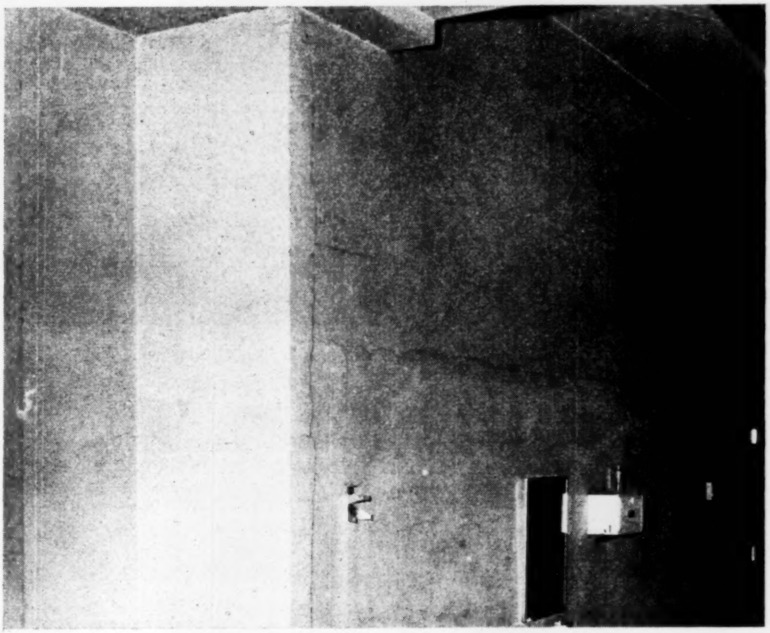

Fig. 4.—Cracking of Plastered Tile Partition in Virginia State Library. Note vertical crack at edge of offset.

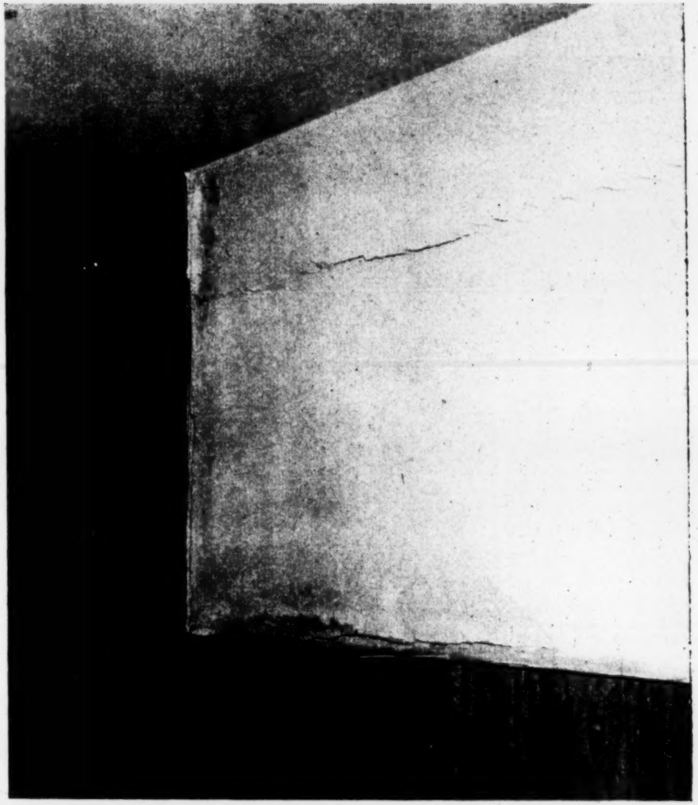

Fig. 5.—Cracking of Plastered Tile Partition in Virginia State Library. Note lifting of plaster edge from marble wainscoting and the horizontal shearing crack in line with the underside of the door lintel.

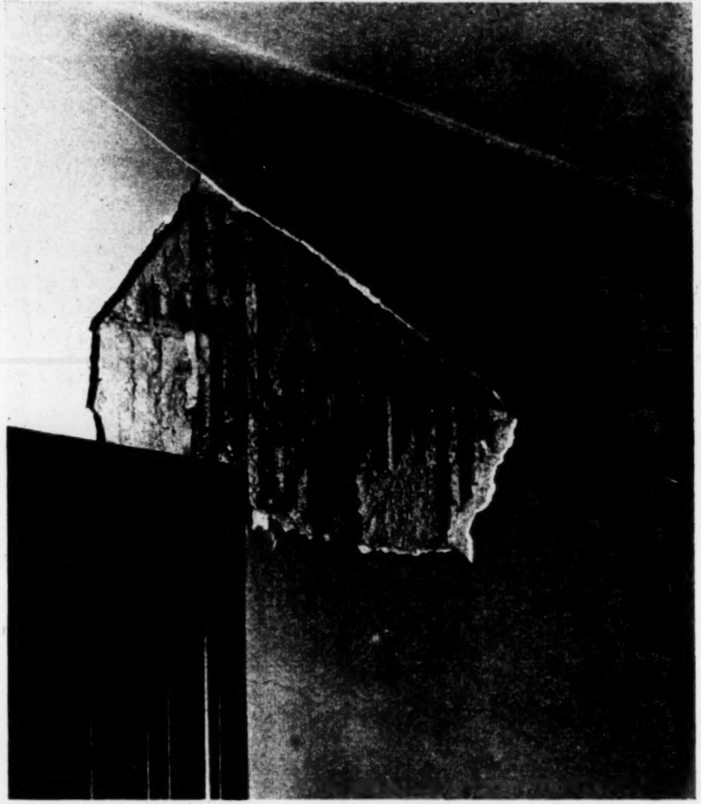

Fig. 6.—Structural Crack in Plastered Tile Partition in Virginia State Library. The exposed tile has crushed and spalled.

main horizontal crack is more conspicuous in Fig. 3. The vertical crack to the right of the offset shown in Fig. 4 can be explained by the horizontal expansion of the wall tending to act on the offset as a couple and causing rotation. Further evidence of horizontal expansion was provided by the characteristic jamming of metal doors set in the tile partitions. The ordinary random map cracking usually ascribed to shrinkage of plaster was relatively rare in this building. One example of random cracking also showed a continuous irregular vertical crack extending from floor to ceiling. The presence of an abutting partition was noted behind this crack.

One effect of vertical expansion is shown in Fig. 5. The tile backing had expanded vertically, lifting the plaster from $\frac{3}{16}$ to $\frac{1}{4}$ in. above the upper edge of the marble wainscoting which was wired to the tile backing. Figure 5 also shows the usual horizontal crack in line with the door lintel. Figure 6 shows spalling of plaster on the fourth story with crushed and spalled tile exposed. A section of tile furring on a concrete wall in the basement "blew out" suddenly as the result of column action when vertical expansion was restrained by contact with the overhead construction.

As a matter of interest, two more of these sudden failures of furring tile were reported to have taken place in basement classrooms of a Washington, D. C., university. As far as could be determined, the source of tile was the same as that in the Richmond structure.

Samples of plaster and mortar and two tiles from the Virginia Library were submitted to the National Bureau of Standards with the request that laboratory examinations be made of these materials for the purpose of determining which component or components of the partitions was causing expansion. Chemical and physical examinations were made on pieces of mortar, using the methods and approach described in the investigation of the St. Joseph's School (1). Autoclave tests on the 8-yr old mortar specimens showed residual expansions of from 0.02 to 0.04 per cent increase in length. Three-year old mortar from St. Joseph's School expanded from 3.3 to 3.6 per cent when autoclaved. Chemical analyses of the Richmond mortar indicated a composition of approximately 1 part portland cement to $\frac{1}{4}$ part of lime to 2 parts of sand by volume, and the total magnesium oxide content did not exceed 0.15 per cent (0.66 per cent of the acid soluble fraction). Differential thermal analyses on grains of lime gave no indication of the presence of either magnesium hydroxide ($Mg(OH)_2$) or magnesium carbonate ($MgCO_3$). It was concluded that the lime was of the high-calcium type and had undergone considerable carbonation. These tests eliminated the mortar as the cause of continuing expansion of the partitions.

Analyses and tests of the plaster samples showed nothing unusual in the materials and proportions. The lime in the white coat was a "normal" dolomitic hydrate, and bulging or blistering of the white coat at 8 yr would have been probable. That no such action occurred may be explained by expansion of the tile base.

The two tiles, identified as "from upstairs" and "from basement," were tested for moisture expansion over the range from room temperature (25 to 30 C) up to 560 C, according to the method of Schurecht as used by Geller and Creamer (7, 8). The tile from "upstairs" had expanded 0.11 per cent and the specimen from "basement," 0.07 per cent. The thermal expansion curves for the "basement" tile are presented in Fig. 7. Curve *A-B′* represents the thermal expansion of the tile in the as-received condition and curve *A-B* that of the same specimen upon reheating.

Following the convention established by Schurecht, both curves are presented as having the same initial point. Actually curves *A-B* had its initial point at *A′* and coincided with the cooling curve *B′-A′*. It will be noted that a significant departure of curve *A-B′* from curve *A-B* first became evident between 125 and 150 C while above 350 C the two curves are parallel.

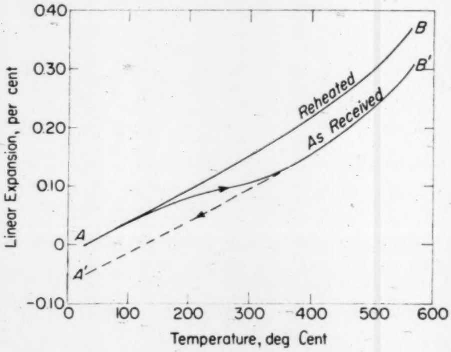

Fig. 7.—Thermal Expansion Curves Made by an Interferometer Method as Used by Schurecht. The test was made on a specimen from a tile partition in the basement of the Virginia State Library.

Since these preliminary tests showed a large moisture expansion in these two samples, 13 additional tile, representing various localities in the Richmond building, were secured and tested for moisture expansion by the method described in the present paper with certain exceptions as noted. Water absorptions by 1-hr boiling according to ASTM Method C 112 - 39,[5] were determined on pieces from 12 of these tile. The results are presented in Table I. The average absorption was 6.9 per cent with a maximum and minimum of 10.5 and 3.7 per cent, respectively, which indicates compliance with the FTX grade of ASTM Specification C 212 - 52 T.[6]

The test specimens were cut with silicon carbide blades without using water or other lubricant. The holes for insertion of the drive screws were also drilled dry. All test specimens were stored in a constant temperature room at 70 F and 55 per cent relative humidity and then measured by two operators. Their measurements checked within ± 0.0005 in. Twelve specimens were then autoclaved by the method of C151[4] and remeasured. The increases in length expressed as percentages of the as-received lengths are reported in column *2* of Table II. The remaining test pieces including two strips cut from tile No. 7 were (*a*) immersed in water for 72 hr at 70 F and then remeasured (column *3*), (*b*) autoclaved and remeasured (column *4*), (*c*) oven dried for 48 hr at 110 C (230 F) (column *5*), and finally (*d*) heated in furnace for 1 hr at 400 C (752 F) and again measured (column *6*).

TABLE I.—WATER ABSORPTION OF TILE FROM VIRGINIA STATE LIBRARY DETERMINED BY 1-HR BOILING.

Tile	Absorption as Percentage of Dry Weight
1	9.0
2	10.5
3	6.4
4	10.2
5	4.9
6	5.9
7	3.9
8	9.9
9	4.9
10	3.7
11	7.9
12	6.1
Average	6.9

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[5] Standard Methods of Sampling and Testing Structural Clay Tile (C 112 - 52), 1952 Book of ASTM Standards, Part 3, p. 450.

[6] Tentative Specifications for Structural Clay Facing Tile (C 212 - 52 T), 1952 Book of ASTM Standards, Part 3, p. 434.

From the observations and measurements made on these samples of materials from the Virginia State Library Building, the following conclusions and comments appear justified:

TABLE II.—MOISTURE EXPANSION TESTS OF TILE FROM VIRGINIA STATE LIBRARY.

Tests were made in the order indicated reading from left to right and are expressed as percentages of the "as-received" length.

Designation of Test Specimen[a]	Autoclaved, 3 hr at 295 psi, per cent	Submerged in Water for 72 hr, per cent	Autoclaved, 3 hr at 295 psi, per cent	Oven Dried, 48 hr at 110 C, per cent	Heated for 1 hr at 400 C and Cooled, per cent	Differences, column 4 and 6, per cent
1	2	3	4	5	6	7
1-1	...	+0.002	+0.071	+0.060	−0.165	0.232
1-2	+0.077	...	...	...	...	...
2P1-1	+0.086	...	...	...	...	...
2P1-2	...	+0.004	+0.066	+0.027	−0.112	0.178
3-1	+0.082	...	...	...	...	...
3-2	...	+0.001	+0.085	+0.069	−0.091	0.176
4P-1	...	+0.001	+0.079	+0.032	−0.102	0.181
5-1	...	−0.007	+0.074	+0.082	−0.039	0.113
5-2	+0.095	...	...	...	...	...
6-1	+0.081	...	...	...	...	...
6-2	...	−0.002	+0.086	+0.054	−0.090	0.176
7-1	...	−0.003	+0.020	+0.034	0.000	0.020
7-2	...	−0.001	+0.023	+0.035	−0.002	0.025
8P1-1	+0.084	...	...	...	...	...
8P1-2	...	+0.017	+0.076	+0.046	−0.296	0.372
9-1	0.084	...	...	...	...	...
9-2	...	−0.004	+0.078	+0.070	−0.180	0.250
9S-1[b]	+0.086	...	...	...	...	...
10P1-1	...	−0.001	+0.057	+0.058	−0.198	0.255
10P1-2	+0.076	...	...	...	...	...
11P1-1	...	−0.002	+0.065	+0.022	−0.122	0.187
11P1-2	+0.074	...	...	...	...	...
12P1-1	...	−0.005	+0.069	+0.048	−0.094	0.163
12P1-2	+0.073	...	...	...	...	...
13P1-1	+0.078	...	...	...	...	...
Total average	+0.081	0.000	+0.065	+0.049	−0.114	0.179
Comparable average	+0.081	...	+0.073[c]	...	...	...

[a] The numbers (1 to 13) preceding the hyphen were those used by the Engineer for identifying the location of each tile in the structure. The numbers (1 and 2) to the right of the hyphen identify the test pieces cut from the tile.

[b] Specimen 9S-1 was cut normal to the cell direction. All other test specimens were cut parallel to the cell direction.

[c] This average does not include specimens 7-1 and 7-2.

1. In 8 yr the tile had undergone a moisture expansion, averaging 0.114 per cent increase in length, with a maximum of 0.296 (8P1-2) and a minimum of 0.000 per cent (7-1). Although the elapsed time between manufacture and installation of the tile is not known, it appears reasonable to assume that most of this expansion took place in the wall.

2. From the results of autoclave treatments, a further average potential linear expansion of 0.07 to 0.08 per cent might be possible.

3. The analyses and tests of mortar showed nothing in composition or behavior that should cause the continuing expansions of the masonry.

4. The lime in the white coat of the

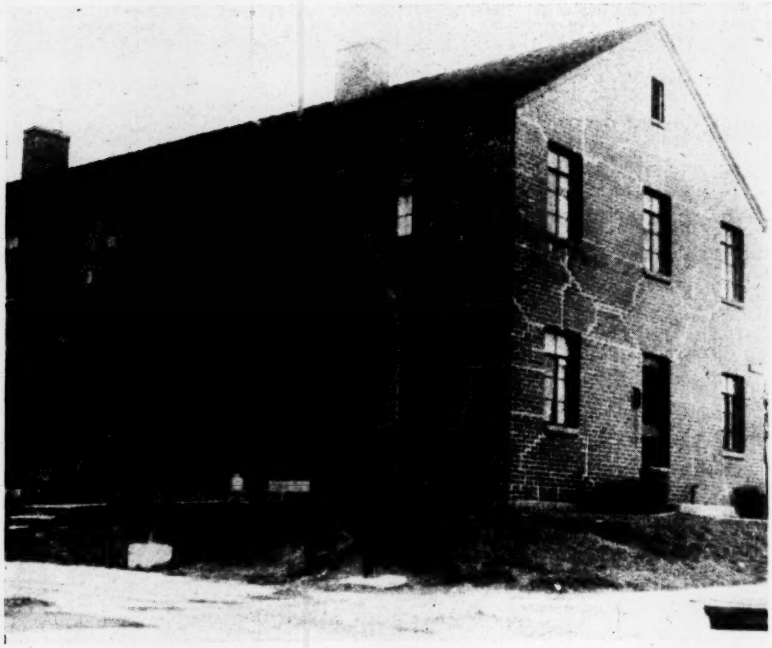

FIG. 8.—Cracking in Brickwork Backed with Structural Clay Tile that Has Undergone Moisture Expansion. This is from one of the Lincoln Park Homes buildings in Columbus, Ohio.

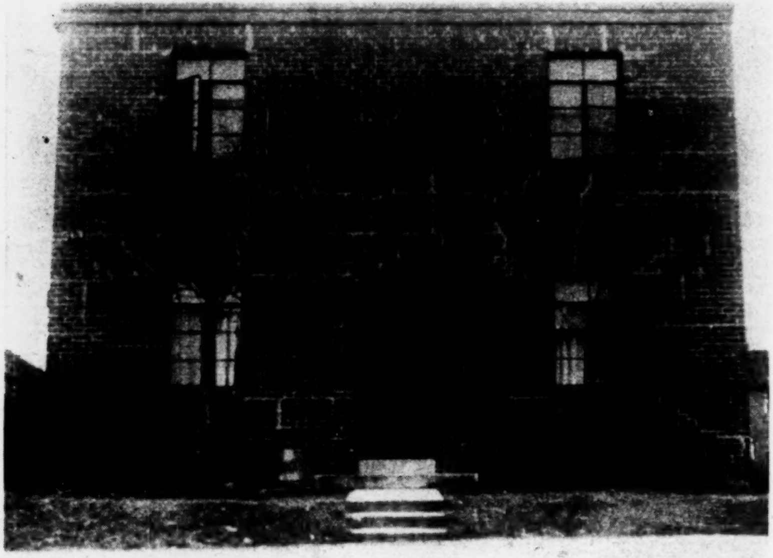

FIG. 9.—View of Another Building in Lincoln Park Homes in Columbus, Ohio.

plaster was a "normal" dolomitic hydrate which frequently causes expansion. Bulging rather than cracking characterizes the behavior of such a lime in plaster.

5. With the exception of specimen 8P1-2, the effect of immersion in water for 72 hr at 70 F was negligible in causing change in length. Specimen 8P1-2 appeared to be unusually susceptible to moisture expansion in consideration both of its 0.017 per cent increase in length from immersion in cold water and its nearly 0.3 per cent change in length caused by furnace heating. The generally negligible effect of the cold soaking appeared, however, to justify use of water as a lubricant in subsequent cutting of test specimens.

6. The correlation between water absorption and moisture expansion of these tile is poor. Specimen 10P1-1, for example, had a water absorption of 3.7 per cent associated with the high moisture expansion of 0.198 per cent. Specimen 7-1, on the other hand, with almost the same absorption (3.9 per cent), had no detectable moisture expansion.

In summary, the movement of the partitions and furring in the Virginia State Library is ascribed to moisture expansion of the tile used in those structures and this expansion may be expected to continue for some years.

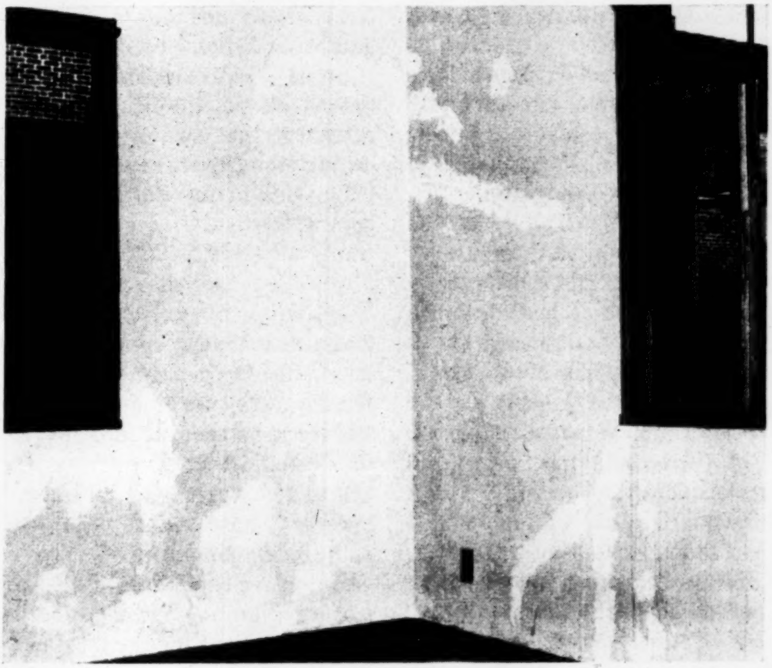

Fig. 10.—Condition of Plaster in an Apartment Room in Lincoln Park Homes. The plaster had been replaced three times and the cracks correspond in position to the exterior cracking in the brickwork.

Lincoln Park Homes, Columbus, Ohio:

This installation consists for the most part of two-story apartment dwelling units supplemented with some one story service buildings. There are 26 of these apartment buildings, thirteen of them having flat roofs and the others having pitched roofs of the gable type. The flat roofs are supported by 2 by 8-in. joists and consist of wood sheathing, insulation, and built-up tar and gravel roofing. The pitched roofs are of similar construction except for the exterior covering which is red tile. The exterior walls are of face brick backed with load-bearing structural clay tile laid in side construction. The floors of the dwelling units are of wood construction except for the floors of the first-story apartments which are concrete when placed on grade. The tile walls are supported on foundations of concrete block, which in turn are supported on poured concrete footings.

This construction was completed in March 1942 and, according to records submitted through Mr. Tesone of the Public Housing Authority, the masonry walls developed cracking shortly after completion. The cracking has continued to date (1954) with both formation of new cracks and reopening of old cracks that had been repointed. Figures 8 and 9 show typical cracking patterns on the exterior of these buildings. Figure 10 is an interior view of a first-story apartment which, according to report, had been replastered three times. The observed exterior cracking was for the most part limited to the south and west exposures of these buildings which faced the usual prevailing wind directions. The possibility of a structural failure or failures due to adverse foundation conditions was ruled out by tests made by responsible local engineers. In August, 1949, a panel or section of wall cut from one of these buildings and consisting of an unparged brick facing with structural clay tile backing was submitted to the National Bureau of Standards for laboratory examination. In general, the procedures used in examining the masonry materials from the Richmond library were employed.

Interpretation of chemical analyses of the hardened mortar was difficult because the aggregate was a mixture of quartz sand and a sand derived from a dolomitic limestone. A petrographic examination of the mortar showed that, within the limit of precision of the estimate, the mortar was a portland cement - dolomitic lime putty - sand mortar 1:1:6 by volume as specified by the architect. Differential thermal analysis curves obtained on these mortars showed unmistakably the presence of considerable dolomite (from the aggregate), but little or no calcium hydroxide ($Ca(OH)_2$) was indicated. Apparently nearly all of the $Ca(OH)_2$ originally present in the lime putty had carbonated during the 8 yr exposure. From the magnitude of the breaks in the heating curves, it was estimated that the mortar from the tile section of the wall contained 5 per cent of magnesium hydroxide ($Mg(OH)_2$), 50 per cent of dolomite, and about 15 per cent of calcium carbonate ($CaCO_3$) not present as dolomite. Similar estimates for the mortar from the brick portion of the panel indicated 5, 50, and 10 per cent, respectively, for the same compounds. This technique does not show the presence of free calcium or magnesium oxide.

Autoclave expansion tests (3 hr at 295 psi) gave an average increase in length of 0.06 per cent for the mortar from the tile and 0.07 per cent for the brick mortar. Individual values ranged from 0.03 to 0.09 per cent. The conclusion with respect to this mortar is that it may have contributed to the expansion of these structures.

The results of routine laboratory tests on the brick, according to the ASTM Methods C 67[7] are as follows: water absorption by 24-hr cold immersion, 1.8 per cent by weight; water absorption by 5-hr boiling, 3.7 per cent; saturation coefficient, 0.49; initial rate of absorption for 1 min, 5.8 g; modulus of rupture,

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[7] Standard Methods of Sampling and Testing Brick (C 67 – 50), 1952 Book of ASTM Standards, Part 3, p. 414.

1060 psi; and compressive strength, 9620 psi. Each value reported is an average of five. As a matter of interest, these values are in very good agreement with the results of acceptance tests made by an Ohio commercial testing laboratory in 1941. Autoclave and furnace heating tests made on 8-in. prisms cut from these bricks gave no measurable change in length. Values were random within ±0.002 per cent. On the basis of known properties, the cracking could not be ascribed to the brick.

The structural clay tile was a red-burning shale body with water absorption by 1-hr boiling averaging 11.8 per cent and a compressive strength of 1190 psi when tested as side construction tile. These values complied with grade LBS of ASTM Specification C 34.[8]

Three tile, graded by color as light, medium, and dark, respectively, were selected and subjected to moisture expansion tests (furnace heating and autoclaving) as described above under "Preparation of Specimens and Methods of Test." The linear changes from the as-received length are expressed as percentages in the following tabulation:

	Light Color	Medium Color	Dark Color
Change, per cent			
From furnace treatment	−0.116	−0.094	−0.107
Autoclaving	+0.092	+0.099	+0.095
Difference	0.208	0.193	0.202

It is of interest to note that these specimens were subsequently subjected to two more complete cycles of furnace heating and autoclaving. The results were reproducible within the limits of accuracy of the measurements (±0.002 per cent). It was concluded, therefore, that the moisture expansion of these particular tile was completely reversible under the conditions of these experiments.

From the foregoing investigations and tests, it was concluded that the principal cause of the cracking observed in the masonry walls of the Lincoln Park Homes was the moisture expansion of the structural clay tile backing. Delayed hydration and consequent expansion of the originally unhydrated magnesium oxide content of the mortar may have contributed to the cracking of the masonry. In this connection two additional structures were reported to have been built with the same tile at about the same time (1942). One of these buildings is said to have cracked, though not to the degree observed on the housing development. The other building was reported as not having cracked when examined in 1949. No information on mortar or design was provided.

Although the expansion upon autoclaving of the tile from the Lincoln Park Homes indicated that an additional expansion (linear) of approximately 0.1 per cent could occur in addition to the expansion of 0.1 per cent that had already taken place, it is uncertain whether ordinary conditions of exposure, even for a very long time, would produce the degree of expansion resulting from autoclaving. In other words, those portions of the masonry that have already cracked may not be expected to double the existing amount of cracking or double the width of existing cracks. On the other hand, those walls (north and east) now showing little cracking, might be expected to crack in the future.

Mr. George Marshall, Attorney for the Columbus Metropolitan Housing Authority, provided the following information in a letter dated January 21, 1954:

> "During the summers of 1951, 1952 and 1953, the entire brick surfaces of this project were regrouted with a thin paste made up of Ottawa sand (very fine white lake sand),

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[8] Standard Specifications for Structural Clay Load-Bearing Wall Tile (C 34 – 52), 1952 Book of ASTM Standards, Part 3, p. 424.

cement and a water proofing compound. This was painted over the entire surface of the building and when it was set up the workers took a burlap sack and washed off the surface of the brick which restored the general appearance but without removing the material which had gone into the cracks and crevices. The local housing authority is very well pleased with the results of this restoring process, but small cracks are beginning to show in the buildings which were treated three years ago and it is now contemplated that the same process might be repeated once more in another several years. While the rooms are now free from moisture and rain, the damage caused by the original water coming through the walls is being rectified from time to time by replastering the interior walls of the respective apartments."

Federal Office Building in Metropolitan Area of Washington, D. C.:

The original structure was completed in September, 1941, and consisted of a three-story concrete frame building approximately 780 ft long with seven wings each about 400 ft long. In July, 1943, a fourth story was added and, in September, 1944, an eighth wing. Each story of the main building was served by a corridor 700 ft long and 10 ft high formed by two partitions of unplastered clay facing tile 6 in. in thickness. Access to offices on both sides of the corridors in the three lower stories is by 138 metal doors. These doors are usually 20 ft center to center and come approximately midway between columns or pilasters which are on 20-ft centers. The length of masonry between doors varies from 16 to 18 ft. The corresponding doors on the fourth floor are wood. According to the original plans, the clearance of the masonry around the metal door bucks was $\frac{3}{32}$ in. "Jamming" of metal doors was first reported in October, 1946. In May, 1950, the main floor corridor was inspected and samples of tile and mortar were submitted to the National Bureau of Standards for examination shortly thereafter. As of 1951, a total of 104 out of 138 doors in the three lower stories had required resetting to relieve jamming. No trouble on the top story or in the wings was reported and no further reports of jamming have been received since 1951.

A careful inspection of the first story corridor indicated the presence of a few 45-deg hair cracks in the bed joint separating the tile course which continued above the door from the course immediately below which abutted on the door frame. A few similar diagonal hair cracks were noted in the bed joints separating the base course from the next course above. This diagonal cracking was barely detectable and would probably not be a cause of concern. If, however, the partitions had been plastered, it is probable that easily noticeable cracks resembling those shown in Fig. 3 would have formed in the plaster over these bed joints.

The contractor had been given the choice of several mortar combinations involving ingredients such as portland cement, white portland cement, nonstaining cement, or slag cement, mixed with from $\frac{1}{2}$ to 1 part of lime putty such as $1:\frac{1}{2}:4$ or $1:1:6$ cement-lime-sand proportions by volume. The magnesium oxide (MgO) content was determined by analysis to be 0.5 per cent. No other examinations of mortar were made.

Two tile, identified as "A" and "B" and having dimensions of 12 by 5 by 6 in. were received, examined, and tested. These specimens resembled the Richmond, Va., tile in that both were fireclay bodies and both had about the same degree of firing as indicated by water absorption. They were, however, the product of a different manufacturer. Pieces of tiles A and B were weighed, oven dried and subjected to 24-hr cold water immersion and 1-hr boiling with the following results:

Tile	Water Content as Received, per cent	Absorption by 24-hr. Immersion, per cent	Absorption by 1-hr Boiling, per cent
A.........	0.64	5.76	7.15
B.........	0.33	3.98	5.80

Six prisms, approximately 9.4 in. in length, were cut from each of the two tiles and tested for moisture expansion according to the methods previously described. The results are presented in Table III in the order (left to right) in which the tests were made. Note that autoclaving preceded furnace heating for some specimens and followed it for others.

Taking the value of 0.066 per cent for moisture expansion (average of specimens A and B from Table III) and applying this to the 16 to 18 ft of masonry between door frames gives an increase of length of from 0.127 to 0.143 in. The $\frac{3}{32}$ (0.094)-in. clearance specified in the architect's drawings was probably reduced if the masons followed their usual practice of "crowding" the door bucks while laying tile. It appears reasonable to conclude that the measured moisture expansion could account for the observed jamming of door openings.

TABLE III.—MOISTURE EXPANSION TESTS OF TILE FROM FEDERAL OFFICE BUILDING NEAR WASHINGTON, D. C.

Tests were made in the order indicated, reading from left to right and are expressed as percentages of the "as-received" length.

Designation of Test Specimen	Autoclaved, 3 hr at 295 psi, per cent	Preheating, 18 hr at 110–115 C, per cent	Heated for 1 hr at 400 C, per cent	Autoclaved, 3 hr at 295 psi, per cent	Differences, per cent	
					Columns 2 and 4	Columns 5 and 4
1	*2*	*3*	*4*	*5*	*6*	*7*
A-1.....................	...	−0.033	−0.081	+0.054	...	0.135
A-2.....................	+0.060	+0.044	−0.064	...	0.124	...
A-3.....................	+0.061	+0.043	−0.065	...	0.126	...
A-4.....................	...	−0.028	−0.077	+0.054	...	0.131
A-5.....................	...	−0.030	−0.078	+0.052	...	0.130
A-6.....................	...	−0.030	−0.080	+0.058	...	0.138
Averages.............	+0.060	−0.030[a]	−0.079[a]	+0.055	0.125	0.134
B-1.....................	...	−0.019	−0.051	+0.057	...	0.108
B-2.....................	...	−0.015	−0.054	+0.060	...	0.114
B-3.....................	...	−0.020	−0.053	+0.049	...	0.102
B-4.....................	+0.072	+0.066	−0.033	...	0.105	...
B-5.....................	+0.067	+0.061	−0.033	...	0.100	...
B-6.....................	...	−0.017	−0.052	+0.061	...	0.113
Averages.............	+0.070	−0.018[b]	−0.053[b]	+0.056	0.102	0.109

[a] Average does not include specimens A-2 and A-3.

[b] Average does not include specimens B-4 and B-5.

In summary, three examples of damage resulting from moisture expansion of structural clay tile have been described. They illustrate (*a*) the cracking patterns of plaster applied to tile masonry; (*b*) the cracking of brick facing over tile; and (*c*) the jamming of door openings resulting from expansion of masonry built with tile subject to moisture expansion.

Discussion

The methods of test described in this paper, although based upon the principles of Schurecht (3), differ considerably from the techniques used by him. The following discussion considers some of the differences between the two methods and reasons for the changes.

A comparator equipped with a micrometer dial and a micrometer screw was substituted for the interferometer (13) used by Schurecht in his furnace test. The interferometer method much exceeds mechanical comparators in accuracy and sensitivity, but a comparator reading to 0.0001 in. is of sufficient accuracy when used with specimens of the size available from structural clay tile. The substitution of a 10-in. test specimen for the comparatively small disk used with an interferometer should provide a better sampling or averaging of the tile. Among other advantages of the present test method are: (*a*) two readings at room temperature (before and after furnace heating) are substituted for the numerous readings necessary for obtaining the two curves required by Schurecht's method, (*b*) mechanical comparators are more generally available than interferometers in plant laboratories, and (*c*) the operation of a mechanical comparator does not required the degree of training, skill, and attention needed for an interferometer method.

The replacement of Schurecht's 560 C maximum temperature by the 400 C of the present method appears justified since Fig. 7 shows that the initial heating and the reheating curves are parallel above 350 C. Schurecht's choice of temperature was presumably set with the intention of approaching but not exceeding, the inversion point for quartz (572 C).

The substitution of autoclaving at 295 psi for 3 hr for Schurecht's 150 psi for 1 hr is more controversial. All comparisons (**4, 5, 10, 11**) involving the effects of variation in the duration and pressure (temperature) of autoclaving indicate that increase in expansion will result from increase in time of exposure and pressure. The 150-psi pressure used for testing tendency to craze of glazed ware is generally agreed to be satisfactory for that purpose. The concern there is with differential volume change of the glaze and body with resultant cracking and crazing. The reason for using a more severe test in the present investigation is to produce a readily measurable expansion if expansion takes place.

For specification purpose a specimen would be considered unsuitable for use if the autoclave expansion (length) exceeded a given limit. Tentatively, a maximum limit of 0.05 per cent increase in length for tile tested at 295 psi for 3 hr is suggested. The use for which the tile is intended, the age of the specimen, and the kind of exposure before testing would obviously have to be considered in setting an acceptance limit.

From the measurements obtained in connection with the three structures described in the present paper, it is concluded that in 8-yr exposures, approximately one half to two thirds of the maximum possible moisture expansion had taken place. In two of these structures, the Virginia State Library and the Federal office building, the tile was exposed as interior partitions, and, in addition, the Library was air conditioned. The Lincoln Park Homes represented a more severe exposure in that water from wind-driven rain actually penetrated the masonry. With the exception of the Federal office building, recent history of these structures showed continued cracking. The extensive cutting-out of door frames may have relieved or postponed further trouble from expansion in the office building. That a large moisture expansion can result from exposure as partitions in an air-conditioned building indicates the slight amount of water necessary for the reaction. It is suspected that the results reported by Holscher (6) using non-aqueous liquids may have been caused by traces of water in his reagents.

The degree of expansion that will cause observable damage obviously depends upon such factors as amount and nature of restraint, interaction with other materials free from expansion or actually shrinking, and the relative elasticities of the materials involved. Plaster on expanding masonry, for example, brings out cracking patterns corresponding to Lueder's lines and clearly indicates relative motions of different portions of the masonry. In the absence of plaster or correspondingly brittle coatings, expansions of considerable magnitude may take place with very little visible cracking as in the Federal office building corridors. The observed failures of furring tile by column action may represent the combined action of expanding tile with shrinking (shortening) concrete frames.

To the author's knowledge, no remedy for damage to existing masonry resulting from moisture expansion of the units has been found or suggested. The rather meager data indicate that expansion is noticeably continuing after at least 12 yr of exposure. Moisture expansion of structural clay masonry units is, fortunately, rare. To date, only three sources of structural clay tile have been found which exhibit this behavior. The photographs and descriptions in the present paper are offered as aids in identifying similar cases of moisture expansion.

SUMMARY AND CONCLUSIONS

It is well known that certain fired clay bodies will gradually expand through the interaction of water with the body. This effect, known as moisture expansion, has been long recognized as one of the causes of cracking and crazing of glazes on certain ceramic wares. The present paper describes several cases of damage in masonry, built in part with structural clay tile. From laboratory tests of the various masonry materials together with consideration of various other possible causes, moisture expansion of the structural clay tile was established as the cause of the damage. Methods of test for existing moisture expansion and for possible future expansion are described in detail.

Among the principal observations and conclusions are the following:

1. Several cases have been observed where moisture expansion of structural clay tile is of such magnitude as to cause cracking of associated plaster and brick veneer, jamming of metal doors, or even the failure of furring through column action.

2. Specimens cut from tile from structures suspected of having expanded were tested by heating to 400 C and measuring the change in length at room temperature caused by such heating. A decrease in length was assumed to measure the moisture expansion that had occurred since the tile were originally fired. Specimens of tile from the three buildings described in the present paper had undergone average moisture expansion (increase in length) in a period of 8 yr of from 0.066 to 0.114 per cent. Expansion of individual specimens ranged from 0.000 to 0.296 per cent.

3. The correlation between moisture expansion and water absorption was poor for the tile specimens examined in this investigation.

4. The average potential future moisture expansion of these tile ranged from 0.056 to 0.099 per cent based on the measured expansion by autoclaving for 3 hr at 295 psi.

5. At an exposure age of 8 yr, moisture expansion of from one half to two

thirds of the total potential expansion had occurred.

6. According to available field reports, moisture expansion as indicated by continued cracking is still occurring after 12 yr of exposure.

7. Moisture expansion apparently does not require contact with free water but may occur in interior partitions and furrings. One example was found in interior partitions of an air-conditioned building.

8. Moisture expansion of structural clay tile of sufficient magnitude to cause damage appears to be rare. Such expansions have been observed to date for tile from only three sources.

Acknowledgments:

In addition to those mentioned in the body of this paper, acknowledgments are made to the following: L. S. Wells and Walter F. Clark for their examinations and advice on mortars, S. M. Lang for making the interferometer measurements on the Virginia State Library tile, Murray M. Sparks for working out the details of tests on the same tile, Melvin R. Herrmann and Wm. C. Green for their laboratory work on the Lincoln Park Homes specimens, and James H. Williamson who made the tests on the Federal office building tile and first prepared a description of the test methods.

REFERENCES

(1) J. W. McBurney, "Cracking in Masonry Caused by Expansion of Mortar," *Proceedings* Am. Soc. Testing Mats., Vol. 52, p. 1228 (1952).

(2) H. G. Schurecht and G. R. Pole, "Effect of Water in Expanding Ceramic Bodies of Different Compositions," *Journal*, Am. Ceramic Soc., Vol. 12, No. 9, pp. 596–604 (1929).

(3) H. G. Schurecht, "Methods for Testing Crazing of Glazes Caused by Increases in Size of Ceramic Bodies," *Journal*, Am. Ceramic Soc., Vol. 11, No. 5, pp. 271–277 (1928).

(4) R. G. Mills, "The Use of the Autoclave in Testing Ceramic Products for Resistance to Crazing," *Journal*, Am. Ceramic Soc., Vol. 13, No. 12, pp. 903–914 (1930).

(5) C. C. Treischel, "Some Notes on Moisture Expansion Tests," *Ceramic Age*, Vol. 25 No. 2, pp. 46–48 (1935).

(6) H. H. Holscher, "Effects of Autoclave Treatments on Ceramic Bodies and Clays," *Journal*, Am. Ceramic Soc., Vol. 4, No. 3, pp. 207–218 (1931).

(7) R. F. Geller and A. S. Creamer, "Moisture Expansion of Ceramic White Ware,' *Journal of Research*, Nat. Bureau Standards, Vol. 9, No. 2, Sept. 1931, pp. 291–309 (1932), (*RP 472*).

(8) R. F. Geller and A. S. Creamer, "Measurement of Moisture Expansion," *Ceramic Age*, Vol. 29, No. 1, pp. 9–10 (1937).

(9) R. F. Geller and A. S. Creamer, "Note on Moisture Expansion of Ceramic Whiteware in Storage and in Service," *Journal*, Am. Ceramic Soc., Vol. 24, No. 3, pp. 77–79 (1941).

(10) R. D. Hill, "The Rehydration of Fired Clay and Associated Minerals," *Transactions*, British Ceramic Soc., Vol. 52, No. 11, pp. 589–613 (1953).

(11) L. Bullin and K. Green, "Crazing of Wall-Tiles," *Transactions*, British Ceramic Soc., Vol. 53, No. 1, pp. 39–63 (1954).

(12) John H. Koenig, "Standard Autoclave Tests for Glazed Whiteware Products," ASTM BULLETIN No. 179, January, 1952, pp. 51–53(TP1).

(13) George Merrit, "Application of the Interferometer to Measurement of the Thermal Dilation of Ceramic Materials," *Scientific Paper No. 485*, Nat. Bureau Standards (1924).

DISCUSSION

Mr. Walter C. Voss[1] (*by letter*).—The author is to be commended for calling attention to another one of several causes for the cracking of masonry walls. We must now add the possibility of so-called "moisture expansion of structural clay tile" to the already existing and reported causes, such as:

1. Structural movements which involve settlements, structural consolidation, deflection effects, and unusual restraint;
2. Mortar expansion;
3. Differential thermal expansion; and
4. Normal, differential expansion caused by water absorption.

While this discussion omits all references to the causes listed above, it is well to keep in mind that several or all of them may be operating jointly to produce or even to relieve cracking tendencies. In addition, it must be remembered that movements for whatever reason quite frequently are misinterpreted because of a lack of consideration of possible hysteresis on return to normal starting condition.

With particular reference to Mr. McBurney's paper, I find it difficult to accept the statement: "The length of the specimen after furnace treatment was assumed to be the same as the length after firing in the kiln." When this is considered in the light of "the assumption (*a*) that clay bodies had their least size after cooling from their original firing in the kiln," it must be assumed that the author considered the specimen after furnace treatment to be of minimum length. When these relationships are coupled with assumption (*c*), given under Heating Test, it appears that the variation in length after reheating and "as received" is entirely assessed to the "hydration of certain constituents of the clay body," which appears under assumption (*b*). This hypothesis ignores any elements of internal hysteresis resulting of distention and extension, which may from operative.

The assumption on the part of the author that an autoclave test as described would establish the end point of possible future expansion is at least bold but subject to considerable question. There is no evidence that such a test produces results similar to normal exposure and the conditions surrounding any particular installation will greatly affect the time required to produce the so-called "moisture expansion" by hydration.

While the paper calls attention to the possibility of potential expansion in certain tile bodies and may suggest a test for establishing some criteria of acceptance, such tests should be used with caution and should be interpreted in the light of other contributing causes before the decision is made to condemn the tile for certain uses. Provisions for stress relief and variations in the details of the wall and its constituent materials may well confine the expansion described in this paper to extremely secondary rôles.

Mr. John C. Thornton[2] (*by letter.*)—Several months before Mr. McBurney's paper was presented, the writer was discussing masonry problems with the author and he mentioned the work he was doing on expansion of structural clay tile. This conversation came back to me when we had a case of severe cracking in masonry walls for which there was no apparent reason.

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[1] Consultant, Architectural Construction and Materials, Cambridge, Mass.

[2] Architect, Royal Oak, Mich.

We were requested to make a report on the cause of cracking in the walls of a substation erected in 1950. The building is approximately 50 ft long by 25 ft deep, one story high with steel roof deck. The floor slab is on the ground 6 in. above grade. Attached at the rear are two transformer enclosures slightly higher than the building and without roofs. The walls of the building are face brick exterior and a salt-glazed tile interior with masonry bond. The transformer enclosures have the same face brick exterior, but the backup is of cinder block, used to lower transformer hum. The footings are of concrete and the foundation walls are of concrete block.

Inspection of the building revealed that there were a number of cracks in the face brick and that they occurred on all four elevations, but that there were no cracks in the interior salt glazed tile. On the interior it was noticed that there were openings at the ends of the continuous window sills and that there appeared to be a movement of the wall at the floor line. There were no cracks in the brickwork of the transformer enclosures. One crack was found in the all-cinder-block dividing wall between the enclosures, due no doubt to shrinkage of the concrete units. Excavations were made at four places where cracks continued to grade, and it was found that they stopped at the floor line. The foundation walls and footings were in perfect condition.

At this point we remembered our conversation with Mr. McBurney. He very kindly furnished us with his methods of test, and samples of the brick and tile were sent to the laboratory to determine if expansion of the interior tile had taken place. We also tested another brick, some new salt glazed tile, and some new ceramic glazed tile. The oven treatment gave an average of -0.038 per cent or approximately $\frac{1}{4}$ in. in the length of the building and the autoclave $+0.128$ per cent. The change in the brick was negligible. These tests showed that without doubt, the cracking in this building was due to the causes Mr. McBurney gives in his paper.

To obtain further information, we inspected several other buildings where salt glazed and ceramic glazed tile had been used for interior finish. These units showed that where the salt-glazed tile had been used there was usually exterior cracking, but that this did not occur where ceramic glazed tile was used. The laboratory tests showed that the ceramic-glazed tile could expand, but no case could be found of expansion in the wall.

An important fact in this study was that the buildings we investigated were kept at a low temperature, except when men were working in them. Condensation on the walls was noticeable in several cases.

Another test was recently made with another salt-glazed tile taken from a power house. Where the building is heated there has been no trouble, but in an ash aisle where it is cold and there is a great deal of moisture, the walls have cracked very severely. Laboratory tests with these tile showed after oven treatment -0.108 per cent or $1\frac{9}{32}$ in. per 100 ft and after autoclaving $+0.19$ per cent or $+\frac{7}{32}$ in. This wall was built over 25 years ago.

We believe in the above cases that the condensation caused by not heating the buildings has contributed to our trouble, for we have not had it with the same tile in heated structures. It also appears that moisture penetrates a salt-glazed surface but does not enter ceramic-glazed units through the glazed face.

We believe that Mr. McBurney has shown the cause for considerably more masonry wall failures than he realized when he wrote the paper.

MR. J. W. MCBURNEY (*author's closure*).—The comments by Mr. Voss on the need for considering other contributing causes are very timely. Note the next to the last paragraph at the end of the author's discussion (page 1237). The use of the word "assumption" was unfortunate. Few observations and explanations of behavior of ceramic bodies are as firmly established today as these "assumptions" made by H. G. Schurecht between 1922 and 1928. His 150-psi autoclave test is standard in the glazed brick and tile and the whiteware industries. He had experimented with 75-psi autoclaving and demonstrated that this was not severe enough to cause crazing of glazes on bodies which crazed from 4 years' exposure to weather. The 295-psi test used in the present paper should be more severe than Schurecht's 150 psi method (see Treischel (5)). If a still more severe test is needed, increase in time of autoclaving rather than increase in pressure would be recommended (see references (10) and (11)).

The author, however, is none too sure now that the results of the 295-psi autoclave expansions may not ultimately be exceeded by tile in the Richmond Library and the Lincoln Park homes. Cracking is continuing after 12 years according to the latest reports. The "assumption" for which the author has no proof is that the 0.05 per cent limit on autoclave expansion gives assurance of freedom from damaging expansion in masonry. Note the qualifications surrounding this suggestion.

Schurecht's experiments in which he cast test specimens in the laboratory and fired to maturity with subsequent treatments including soaking, weather exposure or autoclaving with observed expansions, and later reheating, provided the justification for "assumption *a*." The length after reheating usually corresponded to what might be called the "fired length." Note also the perfect cyclic reversibility for the tile from the Lincoln Park homes. Would not the hysteresis postulated by Mr. Voss have the effect of making the measured expansion less than what actually occurred?

It should be emphasized that the only novelties in the author's paper are the demonstration and illustrations of the effect of moisture expansion in causing the expansion of masonry and in providing "short-cut" methods for detecting previous moisture expansion and predicting its future occurrence or non-occurrence. This paper is only another unit laid on the foundation established by Schurecht. Many research workers have tested and confirmed this foundation.

Mr. Thornton has provided an excellent model of procedure to be followed in establishing the cause of cracking. He first inspected the building for the facts with respect to nature and location of cracks. He then observed what materials were associated with cracking and absence of cracking, thus finding the common factors, and finally he had laboratory tests made to determine the behavior and condition of the suspect materials.

SUMMARY OF PROCEEDINGS OF THE SESSION ON SIGNIFICANCE OF TESTS OF CONCRETE

The Twenty-third Session of the Fifty-seventh Annual Meeting of the Society in Chicago, Ill. on June 16, 1954, was devoted to the presentation of a group of papers on Significance of Tests of Concrete. This session was sponsored by Committee C-9 on Concrete and Concrete Aggregates. These papers are intended to become part of the Symposium on Significance of Tests of Concrete to be issued sometime in the fall of 1955 as *ASTM STP No. 169.* The following five papers were presented:

Mixing and Curing Water for Concrete—W. J. McCoy
Petrographic Examination of Concrete Aggregates—Richard C. Mielenz
Significance of Tests and Properties of Mineral Admixtures—H. S. Meissner
Air-Entraining Admixtures—C. E. Wuerpel
Setting Time of Concrete—E. W. Scripture, Jr.

The paper by Mielenz is being published in this 1954 *Proceedings* and will also be included in the Significance of Tests of Concrete booklet. The remaining papers are being reviewed by the members of Committee C-9 before their inclusion in the Symposium book.

SUPPLEMENT TO SYMPOSIUM OF LATERAL LOAD TESTS ON PILES

Two papers, covering problems of measurement and analysis of lateral earth pressures, deflections, shears, and moments, were presented at the Nineteenth Session of the Fifty-seventh Annual Meeting of the Society in Chicago, Ill, on June 16, 1954. As these papers contained additional data to the Symposium on Lateral Load Tests on Piles sponsored in 1953 by Subcommittee R-10 on Bearing Tests of Soil in Place, Committee D-18 on Soils for Engineering purposes, and published as *ASTM STP No. 154*, it was recommended that they be published as a supplement to the Symposium.

The papers are:

Piles Subjected to Lateral Thrust:
  Part I—Measurement of Earth Pressure and Deflection Along the Embedded Portion of a 40-ft Steel Pile—H. G. Mason and J. A. Bishop

  Part II—Analysis of Pressure Deflection, Moment, and Shear by the Method of Difference Equations—L. A. Palmer and P. P. Brown

These papers and discussions were issued as *ASTM Special Technical Publication No. 154-A* entitled "Supplement to Symposium on Lateral Load Tests on Piles."

SUMMARY OF PROCEEDINGS OF THE SYMPOSIUM ON PERMEABILITY OF SOILS

Subcommittee R-4 on Physical Properties of Soils, Committee D-18 on Soils for Engineering Purposes, sponsored the Symposium on Permeability of Soils, held at the Eleventh and Seventeenth Sessions of the Fifty-seventh Annual Meeting of the Society in Chicago, Ill., on June 15, 1954. In presenting the significant factors which must be considered in order to achieve reliable results from permeability measurements, this Symposium described the latest developments in field sampling and laboratory techniques.

The Symposium included the following papers:

Introduction—E. S. Barber
Principles of Permeability Testing of Soils—Donald M. Burmister
Water Movement Through Porous Hydrophilic Systems Under Capillary, Electric, and Thermal Potentials—Hans F. Winterkorn
Permeability Test for Sands—T. Y. Chu, D. T. Davidson, and A. E. Wickstrom
Low-Head Permeameter for Testing Granular Materials—E. G. Yemington
The Permeability of Compacted Fine Grained Soils—T. W. Lambe
The Permeability and Settlement of Laboratory Specimens of Sand and Sand-Gravel Mixtures—Chester W. Jones
Measurement of the Hydraulic Conductivity of Soil in Place—Don Kirkham
Measurement of Permeabilities in Ground-Water Investigations—W. O. Smith and R. W. Stallman
Selected References on Permeability—A. I. Johnson

These papers with discussions were issued as *ASTM Special Technical Publication No. 163* entitled "Symposium on Permeability of Soils."

SUMMARY OF PROCEEDINGS OF THE SYMPOSIUM ON METHODS OF TESTING BUILDING CONSTRUCTIONS

Committee E-6 on Methods of Testing Building Constructions arranged the Symposium on Methods of Testing Building Constructions held at the Thirty-second and Thirty-third Sessions of the Fifty-seventh Annual Meeting of the Society in Chicago, Ill., on June 17 and 18, 1954.

The Symposium included the following papers:

Introduction—W. T. Savage
Why Test Building Constructions—Herbert L. Whittemore
Structural Performance Requirements in Housing Codes—Lyman W. Wood
Transverse Strength of Masonry Walls—C. B. Monk, Jr.
Fire Tests of Building Structures and Materials and Their Utilization in Building Code Requirements—A. J. Steiner
History and Bibliography of Wood Diaphragm Tests—A. C. Horner
Glued and Nailed Roof Trusses for House Construction—R. F. Luxford and Otto C. Heyer
Lateral Tests on Full-Scale Lumber- and Plywood-Sheathed Roof Diaphragms—J. R. Stillinger
Summary—J. A. Liska

The papers and discussions were issued as *ASTM Special Technical Publication No. 166* entitled "Symposium on Methods of Testing Building Constructions."

AN EVALUATION OF THE SPECIFIC GRAVITY OF AGGREGATES FOR USE IN BITUMINOUS MIXTURES*

By W. C. Ricketts,[1] John C. Sprague,[2] D. D. Tabb,[3] and J. L. McRae[4]

Synopsis

Because aggregates absorb bitumen to a variable extent, no single one of the conventional specific gravities has proved satisfactory for general use with porous aggregates in bituminous mixtures. It is indicated that the proper specific gravity to use ranges from conventional bulk to conventional apparent, its relative numerical value depending upon the quantity and type pores and other characteristics of the aggregate that control the extent to which it is penetrated by bitumen. An erroneous aggregate specific gravity can cause a bituminous mix to be too lean or too rich, with attendant unsatisfactory characteristics. This paper describes what is termed bulk impregnated specific gravity which is a function of the ratio of bitumen to water absorption of an aggregate. This new specific gravity is an outgrowth of development of the Corps of Engineers' procedures for the design and control of bituminous paving mixtures and has been found satisfactory for general use with aggregates used in this connection.

The use of a proper specific gravity for aggregate is of paramount importance in the design and evaluation of bituminous mixtures. The proper specific gravity for one purpose may be quite different from that required for another and yet both may be correct for the purpose intended. In order to obtain a true comparison between theoretical density of a bituminous mixture and the actual density of the pavement, the specific gravity of the aggregate must be known accurately. Also, the specific gravity is used to establish voids criteria, which in turn help to establish the optimum bitumen content. Therefore, any incorrectness in specific gravity adversely affects bitumen content and other characteristics of the mix. The three conventional specific gravities have been used more or less interchangeably for bituminous aggregates, some agencies using bulk, some apparent, and some bulk saturated surface-dry specific gravity; voids criteria of course must be consonant with the specific gravity used. When using aggregate of low absorption (less than 0.5 per cent), the induced error is not too great; but when the more permeable aggregates are used the con-

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13–18, 1954.

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[4] Chief, Bituminous and Chemical Section, Corps of Engineers' Waterways Experiment Station.

ventional gravities can produce unsatisfactory results. Theoretically, when an aggregate absorbs no bitumen, its bulk impregnated specific gravity equals conventional bulk; conversely, if absorbed bitumen equals water absorption, its bulk impregnated specific gravity is equal to apparent specific gravity. The term bulk impregnated specific gravity is used for the specific gravity described herein as being universally applicable for the typical aggregates used in bituminous mixtures; it may be defined as the specific gravity that results in computed voids that are in agreement with limiting criteria for bituminous pavements established on the basis of field behavior.

COMPARISON OF SPECIFIC GRAVITY CONCEPTS

A brief comparison of the conventional specific gravities, defined by the ASTM,[5] and the concept of bulk impregnated specific gravity is illustrated in the interest of clarity:

Bulk Specific Gravity [SG_b].—"The ratio of the weight [A = oven dry] in air of a given volume of a permeable material (including both permeable and impermeable voids normal to the material) at a stated temperature to the weight in air of an equal volume [V_t] of distilled water at a stated temperature": $SG_b = \frac{A}{V_t}$. The volume includes solids and all pores. V_t represents the gross volume of material and is equivalent to conventional $B - C$.[6]

Bulk Specific Gravity, Saturated Surface-Dry Basis (SG_{bs}).—"The ratio of the weight [B = saturated surface-dry weight] in air of a given volume of a permeable material (including both permeable and impermeable voids normal to the material) at a stated temperature to the weight in air of an equal volume [V_t] of distilled water at a stated temperature": $SG_{bs} = \frac{B}{V_t}$. The gross volume includes solids and all pores; the weight includes water absorbed by the permeable pores.

Apparent Specific Gravity [SG_a].—"The ratio of the weight [A] in air of a given volume of the impermeable portion of a permeable material (that is, the solid matter including its impermeable pores or voids) at a stated temperature to the weight in air of an equal volume [$V_t - V_p$] of distilled water at a stated temperature": $SG_a = \frac{A}{V_t - V_p}$, where V_p symbolizes the volume of permeable pores and is equivalent to conventional $B - A$.[6] The volume includes solids and impermeable pores only. Visualize that all permeable pores have been squeezed out, causing a concomitant decrease in volume of rock; the term $V_t - V_p$ represents this net volume and is equivalent to conventional $A - C$.[6]

Bulk Impregnated Specific Gravity (SG_{bi}).—The ratio of the weight, A, in air of a given volume of a permeable aggregate (including solids, impermeable pores and pores normally permeable to water but which are variably permeable to bitumen) at a stated temperature to: the weight in air of an equal volume, V_t, of distilled water at a stated temperature minus the weight of the volume, V_b, of bitumen absorbed by pores which are permeable to it. $SG_{bi} = \frac{A}{V_t - V_b}$. The volume includes solids, impermeable pores, and pores which are permeable to water but which exhibit variable permeability to bitumen. Visualize that all

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[5] Standard Definitions of Terms Relating to Specific Gravity (E 12 - 27), 1952 Book of ASTM Standards, Part 3, p. 1594. Data in brackets and the illustrative symbols have been added by the authors.

[6] Standard Method of Test for Specific Gravity and Absorption of Coarse Aggregate (C 127 - 42), 1952 Book of ASTM Standards, Part 3, p. 967.

TABLE I.—CHARACTERISTICS OF INDIVIDUAL COARSE AND FINE AGGREGATES INCLUDED IN THE SPECIFIC GRAVITY STUDIES.

Type of Aggregate	Ratio $\frac{\mu_b}{\mu_w}$, per cent	Absorption, per cent		Conventional Specific Gravity			Bulk Impregnated Specific Gravity (SG_{bi})
		Water (μ_w)	Bitumen (μ_b)	Bulk Dry (SG_b)	Bulk Saturated (SG_{bs})	Apparent (SG_a)	
Coarse Aggregate (with AC)							
Basalt, spongy	1	11.5	0.1	1.67	1.85	2.05	1.67
Basalt, spongy	5	11.7	0.6	1.65	1.85	2.05	1.66
Basalt, porous	7	2.7	0.2	2.57	2.64	2.75	2.59
Basalt, dense	14	0.7	0.1	2.88	2.90	2.94	2.89
Sandstone	17	4.8	0.8	2.36	2.47	2.66	2.40
Gravel, basaltic	21	2.4	0.5	2.39	2.45	2.54	2.42
Gravel, natural, several types	25	0.4	0.1	2.69	2.70	2.73	2.70
Gravel, rhyolite	26	2.7	0.7	2.36	2.43	2.52	2.40
Gravel, crushed, several types	30	3.0	0.9	2.69	2.77	2.92	2.75
Gravel, natural, several types	30	2.0	0.6	2.63	2.68	2.78	2.67
Gabbro	33	0.6	0.2	2.98	3.00	3.04	3.00
Gravel, crushed, several types	35	2.0	0.7	2.55	2.60	2.68	2.59
Gravel, crushed, several types	36	1.1	0.4	2.58	2.61	2.65	2.60
Quartzitic gravel	38	1.3	0.5	2.55	2.58	2.63	2.58
Granite	40	0.5	0.2	2.65	2.67	2.70	2.67
Quartzite	43	0.7	0.3	2.56	2.58	2.61	2.58
Limestone gravel	50	2.0	1.0	2.48	2.53	2.61	2.54
Limestone, dense	50	0.2	0.1	2.71	2.72	2.73	2.72
Limestone, dense	50	0.2	0.1	2.72	2.72	2.73	2.72
Limestone, Florida	54	2.6	1.4	2.45	2.51	2.61	2.53
Limestone, Florida	55	5.1	2.8	2.22	2.34	2.51	2.37
Limestone, Florida	67	2.7	1.8	2.41	2.48	2.59	2.53
Slag, Woodstock	72	3.2	2.3	2.30	2.38	2.49	2.44
Slag, Birmingham	75	3.6	2.7	2.26	2.34	2.46	2.40
Slag, Youngstown	78	2.7	2.1	2.31	2.37	2.47	2.43
Slag, Birmingham	88	4.0	3.5	2.16	2.24	2.36	2.33
Slag, Birmingham	92	3.6	3.3	2.12	2.20	2.30	2.28
Vesicular (coral)	94	5.2	4.9	2.16	2.27	2.43	2.41
Slag, Ashland	96	1.8	1.7	2.36	2.40	2.46	2.46
Vesicular (basaltic)	100	1.5	1.5	2.70	2.74	2.82	2.82
Fine Aggregate (with AC)							
Sandstone	18	3.4	0.6	2.45	2.54	2.68	2.49
Gravel, crushed rhyolite	24	2.1	0.5	2.41	2.46	2.53	2.44
Gravel, several types	33	2.1	0.7	2.74	2.80	2.92	2.80
Limestone, Florida	52	2.5	1.3	2.50	2.56	2.67	2.59
Limestone, Florida	57	2.3	1.3	2.53	2.60	2.69	2.62
Slag, Youngstown	52	2.3	1.2	2.65	2.71	2.82	2.74
Slag, Birmingham	69	2.6	1.8	2.56	2.64	2.73	2.68

TABLE I.—*Concluded.*

Type of Aggregate	Ratio $\frac{\mu_b}{\mu_w}$, per cent	Absorption, per cent		Conventional Specific Gravity			Bulk Impregnated Specific Gravity (SG_{bi})
		Water (μ_w)	Bitumen (μ_b)	Bulk Dry (SG_b)	Bulk Saturated (SG_{bs})	Apparent (SG_a)	
Coarse Aggregate (with Tar)							
Basalt, porous	20	3.9	0.8	2.54	2.64	2.82	2.58
Sandstone	38	4.8	1.8	2.36	2.47	2.66	2.41
Gravel, basaltic	38	2.4	0.9	2.39	2.45	2.54	2.43
Gravel, rhyolite	41	2.7	1.1	2.36	2.43	2.52	2.40
Gravel, several types	45	1.8	0.8	2.63	2.68	2.78	2.67
Limestone gravel	60	2.0	1.2	2.48	2.53	2.61	2.55
Limestone, Florida	67	2.8	1.9	2.45	2.51	2.61	2.52
Limestone, Florida	71	5.1	3.6	2.22	2.34	2.51	2.36
Limestone, Florida	79	2.4	1.9	2.41	2.48	2.59	2.52
Slag, Birmingham	83	3.6	3.0	2.26	2.34	2.46	2.41
Slag, Youngstown	96	2.7	2.6	2.31	2.37	2.47	2.44
Slag, Ashland	106	1.8	1.9	2.36	2.40	2.46	2.46

pores which are permeable to bitumen have been squeezed out and that the remainder of the particle has been sealed by a weightless and dimensionless membrane. (So-called "water-permeable" pores range from being completely permeable to completely impermeable to a bitumen; hence $V_b \doteq V_p$ and 0). The term $V_t - V_b$ represents a variable "net" volume, ranging numerically from the gross volume symbolized by V_t to the net volume symbolized by $V_t - V_p$. If the particle absorbs no bitumen, bulk impregnated specific gravity will be numerically equal to bulk specific gravity since V_b, the amount of bitumen absorbed, is zero, and, by definition, $SG_b = \frac{A}{V_t}$. If all the permeable voids are filled with bitumen, bulk impregnated specific gravity will be numerically equal to apparent specific gravity, since V_b will then be equal to V_p, the volume of water absorbed by the material and, by definition, $SG_a = \frac{A}{V_t - V_p}$. If the permeable voids are partially filled, the bulk impregnated specific gravity will be somewhere between bulk and apparent specific gravity, the location depending upon the degree of absorption of bitumen.

DISCUSSION OF PROCEDURE AND RESULTS

The procedure developed in this investigation, originally outlined in an unpublished report dated June 12, 1947, for determining bulk impregnated specific gravity for bituminous aggregate is predicated on the fact that porous aggregates absorb variable amounts of bitumen in bituminous mixtures, and that it is a form of gravity ranging between dry bulk and apparent specific gravities, its position in that range depending upon the relative amount of bitumen absorbed. Figures 1 and 2 show photographs of sections of aggregates typifying this absorption. Some fifty typical aggregates and combinations of aggregate were obtained from various sections of the country for this investigation; the results shown in Tables I and II are averages obtained with the use of the different bitumens used. The aggregates

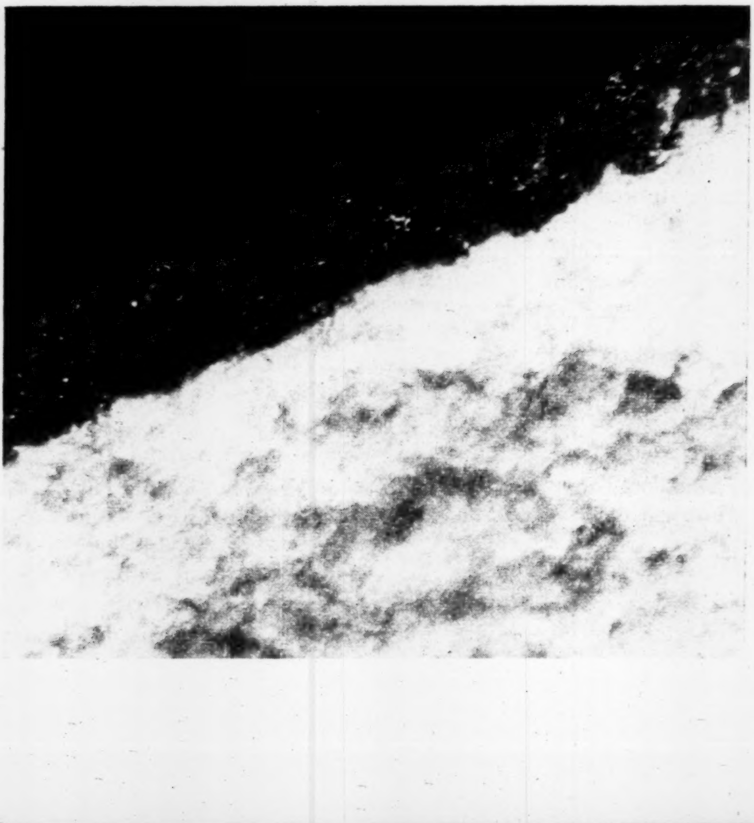

FIG. 1.—Limestone Gravel Impregnated with Asphalt Cement.

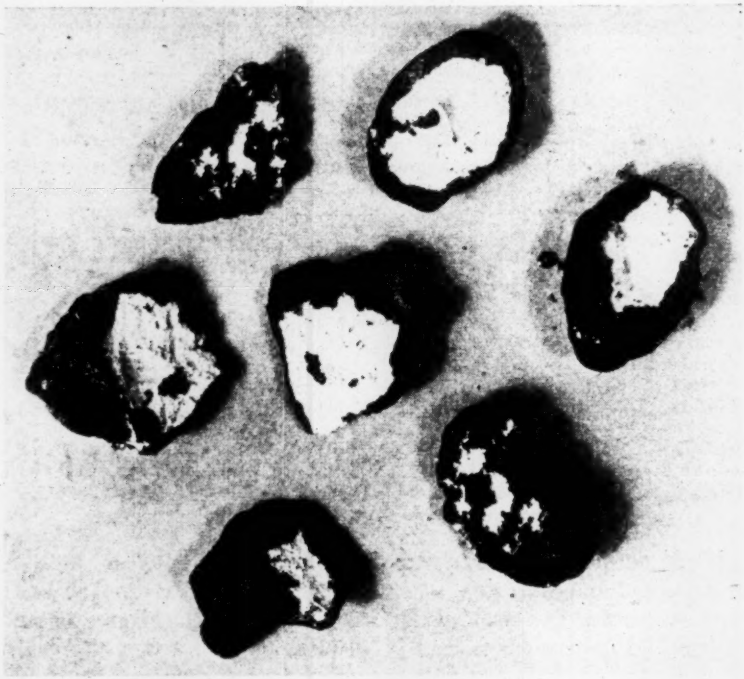

FIG. 2.—Florida Limestone Impregnated with Asphalt Cement.

are grouped in accordance with broad similarity of characteristics. As will be noted below there is also coincidence in this grouping from the standpoint of the ratio of absorption of bitumen to water. In developing the procedure, which is described in the Appendix, it was felt that soaking the aggregate in a bitumen bath at conventional temperature for a limited time would, from a practical standpoint, produce satisfactory specific gravity values. In order to get some idea of the effect of varying this soaking time, tests were made on companion aggregates soaked in hot asphalt for periods ranging from 5 min to 2 hr. Additional samples were soaked in hot asphalt for 15 min and then stored for 7 days at room temperature. The very slight differences obtained, Table III, were not considered of sufficient magnitude to affect adversely the accelerated test in adequately simulating prototype conditions. The procedure is applicable to coarse and fine aggregates and to blended aggregates including the mineral filler. However, it is not applicable to the mineral filler alone because of the problem of entrapped air. The conventional apparent specific gravity is used for mineral filler *per se.*

TABLE II.—CHARACTERISTICS OF BLENDED AGGREGATES INCLUDED IN THE SPECIFIC GRAVITY STUDIES.

Type of Aggregate	Ratio $\frac{\mu_b}{\mu_w}$, per cent	Absorption, per cent		Conventional Specific Gravity			Bulk Impregnated Specific Gravity (SG_{bi})
		Water (μ_w)	Bitumen (μ_b)	Bulk Dry (SG_b)	Bulk Saturated (SG_{bs})	Apparent (SG_a)	
Uncrushed chert gravel, sand and limestone dust	45	2.0	0.9	2.52	2.57	2.65	2.58
Blend of slag (+ No. 4) and crushed limestone plus fine river bar sand and limestone dust (− No. 4)	50	1.8	0.9	2.50	2.54	2.60	2.55
Crushed limestone, limestone screenings and natural sand	50	0.8	0.4	2.65	2.67	2.72	2.69
Florida limestone	53	3.6	1.9	2.43	2.52	2.66	2.55
Crushed gravel, sand and limestone filler	56	2.5	1.4	2.47	2.53	2.65	2.57
Sandstone	57	5.6	3.2	2.32	2.45	2.64	2.50
Coral, Bermuda	73	4.5	3.3	2.34	2.45	2.63	2.55
Coral, Coopers Island, Bermuda	76	6.8	5.2	2.26	2.43	2.69	2.59
Vesicular basalt	86	1.5	1.3	2.86	2.91	3.00	2.98
Florida limestone, limestone screenings and sand	...	...	...	...	...	2.59	2.36
Crushed limestone, limestone screenings and natural sand	...	...	...	...	...	2.73	2.69
Crushed limestone, limestone screenings and natural sand	...	...	...	...	...	2.72	2.68

An inspection of the various groups of aggregates in Table I indicates that variation between kinds of specific gravity is a function of pore type and other aggregate characteristics, as well as of the amount of pore space in the aggregate. A comparison of the sandstone coarse aggregate and the vesicular coral, for example, having substantially the same amount of water absorption, brings this out clearly. It will be noted that there is significant difference in ratio of bitumen absorption, μ_b, to water

TABLE III.—EFFECT OF SOAKING PERIOD IN ASPHALT CEMENT ON BULK IMPREGNATED SPECIFIC GRAVITY.

[illegible]	Type of Coarse Aggregate	Bulk Impregnated Specific Gravity (SG_{bi})
Aggregate Soaked at 280 F for 15 Min		
No. 6	Gravel, basaltic	2.42
No. 14	Quartzitic gravel	2.58
No. 16	Quartzite	2.58
No. 17	Limestone gravel	2.54
No. 18	Limestone, dense	2.72
No. 22	Limestone, Florida	2.53
No. 24	Slag, Birmingham	2.40
No. 25	Slag, Youngstown	2.43
No. 26	Slag, Birmingham	2.33
No. 29	Slag, Ashland	2.46
Aggregate Soaked at 280 F for 5 Min		
No. 6	Gravel, basaltic	2.43
No. 16	Quartzite	2.56
No. 18	Limestone, dense	2.71
No. 22	Limestone, Florida	2.54
No. 24	Slag, Birmingham	2.43
Aggregate Soaked at 280 F for 2 Hr		
No. 6	Gravel, basaltic	2.43
No. 16	Quartzite	2.59
No. 22	Limestone, Florida	2.52
No. 24	Slag, Birmingham	2.39
No. 29	Slag, Ashland	2.47
Aggregate Soaked at 280 F for 15 Min, in Air for 7 Days		
No. 6	Gravel, basaltic	2.43
No. 14	Quartzitic gravel	2.59
No. 16	Quartzite	2.59
No. 17	Limestone, gravel	2.54
No. 22	Limestone, Florida	2.53
No. 25	Slag, Youngstown	2.44
No. 26	Slag, Birmingham	2.34
No. 29	Slag, Ashland	2.46

absorption, μ_w, and that the bulk impregnated specific gravity of the sandstone approximates bulk specific gravity whereas that of the coral is near apparent specific gravity. The porous basalt and Youngstown slag serve as another striking example. The same general relationships obtain with blended coarse and fine aggregates, as is brought out in Table II. Figure 3 is plotted from data shown in the tables in order to illustrate this trend more clearly. The points are shaded for coarse, open for fine, and half-shaded for blended aggregate. The illustration shows at a glance the relationship of bulk impregnated specific gravity to the conventional specific gravities for a wide range of aggregate characteristics. The abscissa, of course, is an abstract concept used to complete the illustration. It will be noted that there is a substantially linear increase, percentagewise, in the specific gravity with increase in the ratio of bitumen to water absorption and that the numerical relationship between bulk impregnated and the conventional specific gravities progresses from equality with bulk when the ratio is zero, through bulk saturated surface-dry when the ratio is in the 25 to 65 per cent zone, to equality with apparent when the ratio approaches 100 per cent. It is also observable that broad classes of aggregates group in each of these ranges; for example, the slags and other vesicular rocks approach or are equal to apparent specific gravity. Likewise, the calcareous and most of the siliceous and igneous rocks fall in a numerical range approximating bulk saturated surface-dry specific gravity, while the basalts and sandstone approach or are equal to bulk specific gravity. In general, then, it might be said that bulk saturated surface-dry specific gravity is suitable for use with most of the coarse siliceous and calcareous aggregates and that apparent specific gravity is suitable for use with most of the coarse slags and other vesicular aggregates, while bulk specific gravity appears suitable for use with certain aggregates such as some coarse basalts. However, there are a sufficient number of exceptions which, coupled with the changes in trend with increased fineness

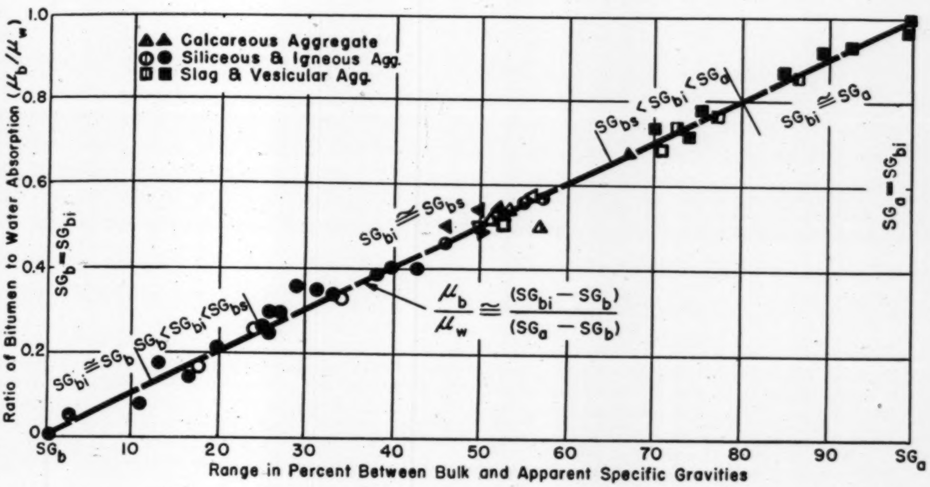

FIG. 3.—Interrelationship Between Ratio of Bitumen to Water Absorption and Specific Gravity Range.

of aggregate, makes such a generalization too uncertain for successful use.

An example of how the different specific gravities can affect a bituminous mixture is illustrated below:

	Percentage of Mix	Absorption of Fractions, per cent	Specific Gravity, SG_b	Specific Gravity, SG_{bs}	Specific Gravity, SG_a	Specific Gravity, SG_{bi}
Birmingham Slag +⅜	24	5.1	2.09	2.20	2.34	2.29
Birmingham Slag −⅜	21	2.7	2.38	2.45	2.55	2.52
Limestone Screenings	44	2.1	2.50	2.55	2.64	2.58
Local Sand	11	0.8	2.60	2.62	2.66	2.62
Theoretical density			136.2	139.6	144.5	142.1
Acutal density			136.6	136.6	136.6	136.6
Voids—total mix, per cent			−0.3	2.1	5.5	3.9
Crushed Granite	50	0.6	2.61	2.63	2.65	2.63
Washed Granite Screenings	33	0.3	2.68	2.69	2.70	2.69
Unwashed Granite Screenings	17	0.3	2.67	2.68	2.69	2.68
Theoretical density			150.2	150.9	151.6	150.9
Actual density			145.7	145.7	145.7	145.7
Voids—total mix, per cent			3.0	3.4	3.9	3.4

A study of these data show that "apparent" results are obtained which are dependent upon the type of aggregate specific gravity used. It is considered good engineering practice to work for a compacted bituminous mixture having an optimum bitumen content based upon empiric minimum and maximum percentages of voids. The lower limitation precludes overfilling of the voids in a pavement with bitumen and causing bleeding, rutting, and shoving; the higher limit guards against too lean a mix and helps insure impermeability of a pavement. But if the correct aggregate specific gravity is not used, these percentages are misleading. At one extreme there is a tendency for the mix to appear too rich; at the other the mix appears to be on the lean side and of relatively high permeability. Further, the theoretical per cent density could exceed 100 per cent if the proper numerical value for specific gravity is not used. A change of 1 per cent in voids total mix requires an adjustment in the bitumen content of the order of 0.5 per cent. Data in the above tabulations show that for a group of porous aggregates there would be a considerable difference in the asphalt content determined by the use of the various specific gravities, while with the low porosity aggregates the range will be slight.

In the development of the Corps of Engineers' procedures for the design of bituminous paving mixtures, test sections were built which included mixtures at a range of bituminous contents. These were subjected to concentrated traffic of heavy wheel loads. The richer mixes "flushed," as would be expected, and the leaner mixes remained stable. Records were maintained of the density that developed under traffic. These data were used in a study to determine the proper specific gravity to use in computing void requirements. It was found that when bulk specific gravity was used, values of less than zero were obtained for per cent voids total mix of the rich mixes which is an impossibility. When apparent specific gravity was used, the per cent voids total mix of the rich mixes approached 1.5 to 2.0 per cent although on occasion lower values were recorded.

The new procedure for determining the specific gravity of aggregates which is described in detail in the Appendix is being used by the Corps of Engineers, in conjunction with modified voids criteria, to design bituminous concrete pavements.

CONCLUSIONS

Within the limits of test performed upon the materials involved in this investigation it is concluded that:

1. No single conventional specific gravity is satisfactory for general use with all porous aggregates used in bituminous mixtures.

2. Bulk impregnated specific gravity is a function of the ratio of bitumen to water absorption, which varies widely but which follows a definite pattern with different types of aggregate.

3. All of the forms of specific gravity discussed produce substantially the same end result with aggregates of low porosity.

4. Bulk impregnated specific gravity is suitable for general use with all aggregates used in bituminous mixtures and is particularly suited for use with porous aggregates.

APPENDIX

TEST PROCEDURE FOR DETERMINING BULK IMPREGNATED SPECIFIC GRAVITY

The procedure meets necessary requirements for simplicity and reproducibility and is applicable to both coarse and fine aggregates and to blended aggregate including the mineral filler (but not to mineral filler by itself).

Apparatus:

Equipment used in the test is listed below.

(*a*) Large oven, thermostatically controlled, sensitive to 5 F in the approximate range of 225 to 325 F.

(*b*) Balance of approximately 5000-gm capacity, sensitive to 0.1 gm suitably arranged for weighing sample in air and suspended in water.

(*c*) Pails of 1-gal capacity (syrup can with top rim removed to eliminate entrapped air is satisfactory) equipped with wire handle for suspending in water.

(*d*) A suitable large container for immersing the 1-gal pail, and typical assembly for suspending the pail from the center of scale pan or balance.

(*e*) Bake pans of size suitable for retaining approximately 1000 gm of aggregate.

(*f*) One heavy sheet-metal strip about 1 in. wide for stirring contents of each pail.

Samples:

Samples are as follows:

(*a*) *Aggregate.*—Prepare a representative sample of the aggregate (1000 gm of fine aggregate, 1500 gm of coarse aggregate, or 1500 gm of blended aggregate). Care should be taken to insure that the sample represents prototype grading.

(*b*) *Bitumen.*—Obtain a representative sample of about 1 gal of the bitumen that is to be used for the paving mix.

Procedure:

Specific gravity of aggregate is derived as follows:

(*a*) Dry sample to constant weight at a temperature not less than 230 F nor greater than 290 F, cool to room temperature, and weigh to nearest 0.1 gm.

(*b*) Heat asphalt to 280 ± 5 F,[7] and pour sufficient amount into the 1-gal pail to fill it to about one third its depth. Insert the sheet-metal stirrer and allow bitumen to cool to 72 ± 2 F (a minimum of 8 hr is usually required to accomplish this, and preferably it should be allowed to cool overnight).

(*c*) Weigh pail plus bitumen and stirrer in air at any temperature and in water at 72 ± 2 F.

(*d*) Place the pail of asphalt with stirrer and the sample of aggregate in oven at 280 ± 5 F,[7] and leave both until temperatures are equalized (a minimum of 4 hr is usually required).

(*e*) Remove aggregate and bitumen from oven and add aggregate to bitumen, stirring thoroughly as aggregate is gradually added to the hot bitumen; continue stirring until entrapped air has been removed. External vibration may be used to remove air when difficulty is encountered in removing air by stirring. During the cooling period, flame surface to remove air bubbles if such are present. Cool to 72 ± 2 F (should cool overnight).

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[7] These temperatures apply when an average penetration asphalt cement is used; when another type bitumen is used the temperature should be the same as that used under normal field conditions.

(*f*) Weigh pail plus stirrer plus aggregate plus bitumen in air at room temperature and in water at 72 ± 2 F.

Calculation:

Bulk impregnated specific gravity (SG_{bi})

$$= \frac{A}{(D - E) - (B - C)}$$

where:

A = weight of oven-dry aggregate in grams,

B = weight of pail plus stirrer plus bitumen in air,

C = weight of pail plus stirrer plus bitumen in water,

D = weight of pail plus stirrer plus bitumen plus aggregate in air, and

E = weight of pail plus stirrer plus bitumen plus aggregate in water.

DISCUSSION

MR. C. A. CARPENTER[1] (*by letter*).—This paper is a timely and valuable contribution to the science of bituminous mixture design and control. The idea of determining the specific gravity of aggregates by immersion in the asphalt to be used as the binder for the mixture has been discussed for several years and various investigators have made preliminary tests but, as far as I know, this is the first report of an investigation in which emphasis has been placed on the important fact that the *ratio* of asphalt absorption to water absorption was a systematic variable for different types and classes of aggregates. I think this important variable has been overlooked for the most part in the preliminary studies to which reference is made.

It is stated in the paper that corroborative field tests have been made on pavement test sections and that the results are consistent with the relations shown in this paper. (However, it is also stated that the aggregates used in the field studies were relatively nonporous.) In this case, bulk specific gravity, apparent specific gravity, and effective or bitumen-impregnated specific gravity would all be essentially the same and correction of design on the basis of aggregate porosity would not be necessary. Attention is drawn to this fact not to detract in any way from the value of the paper but to call attention to the need for additional field and laboratory correlation in the ranges of highly porous aggregates and aggregates of intermediate porosity where, as has long been known, the porosity of the aggregate does have to be taken into account in setting the bitumen content for a mixture. No data are presented for the field tests so far completed, and it is to be hoped that when data on concurrent field and laboratory studies on a specific group of aggregates having a wide range of porosities become available another report will be offered for publication by Mr. Ricketts, his associates, or others, to complete the picture. It should be pointed out that to provide a good correlation it is essential that the field performance and laboratory design data be obtained on the same aggregates.

A very strong indication that a good field correlation can be so obtained is to be found in the reports of density studies on laboratory mixtures by J. Rogers Martin and Andrew H. Layman, Jr.[2] and James M. Rice.[3] In the work of these authors, the bitumen-impregnated specific gravity of the aggregate was determined by computation after first determining the corresponding specific gravity of the loose bituminous mixture directly from weights in air and in water.

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[1] Assistant Chief, Physical Research Branch, Bureau of Public Roads, Washington, D. C.

[2] J. Rogers Martin and Andrew H. Layman, Jr., "Hot Mix Asphalt Design Studies," Publication No. 75, Oklahoma Engineering Station, March, 1950.

[3] James M. Rice, "New Test Method for Direct Measurement of Maximum Density of Bituminous Mixtures," *The Crushed Stone Journal*, Sept., 1953, p. 10.

After making the necessary computations from the data in these two reports, we have plotted the values μ_{bi}/μ_w *versus* Range, in Per cent, Between Bulk and Apparent Specific Gravity on Fig. 3 of the paper under discussion and find a similar distribution of points to that developed by Ricketts and associates. This appears to be significant since it indicates that aggregates coated with bitumen by normal mixing procedure exhibit variations in bitumen *versus* water absorption over a range similar to that exhibited by aggregate samples immersed in bitumen. It does not, however, prove that any specific aggregate would show the same relative bitumen *versus* water absorption in the mixing process and the bitumen immersion procedure, and this is the factor that needs further study.

If further correlation proves that, generally, immersion in bitumen produces the same degree of bitumen absorption as coating with bitumen in a mixing machine, the simple, straightforward method described in this paper will be fully authenticated as a design tool.

MR. JOHN C. SPRAGUE (*author's closure*).—The authors wish to thank Mr. Carpenter for his valued comments. The work described in this paper was directed toward the design of high type pavement for traffic of very heavy planes, using high quality aggregates of variable porosities. The aggregates selected met the current specified requirements and are typical of those normally used in constructing airfield pavements for military use. Mr. Carpenter, of course, is quite right in stating that the various specific gravities would all be essentially the same for relatively nonporous aggregates, as was pointed out in Conclusion 3 of the paper.

The significance of the ratio of bitumen to water absorption *per se* is that bulk impregnated specific gravity runs the numerical gamut of conventional specific gravities if we consider a wide enough field of aggregates. This demonstrates the inapplicability of conventional gravities for all aggregates used in bituminous mixtures. However, it is not necessary that the asphalt in the bulk impregnated test exactly simulate the degree of penetration that occurs in the actual pavement. The objective is to control the degree of bitumen penetration so that a specific gravity value is obtained which results in computed voids that are in agreement with limiting criteria for bituminous pavements established on the basis of actual pavement behavior.

A SIMPLE FRACTIONAL DISTILLATION TEST FOR CREOSOTE*

By H. L. Stasse[1]

Synopsis

A simple distillation test for determination of the true boiling characteristics of creosote oil is presented. The apparatus is a modification of that used in the Standard Method of Test for Distillation of Creosote (D 246)[2]; a round-bottom flask fitted to a 5-ball distillation column is used in place of the standard flask.

Distillation data were obtained on creosotes of varying distillation characteristics using the standard test and the 5-ball column test. Comparison of these data with composition according to boiling points as obtained by careful fractionation indicates that at temperatures of 315 C and below results by the 5-ball column method agree closely with data obtained by fractionation, whereas results by the standard test have little significance as an indication of true boiling characteristics.

The distillation characteristics of creosote oils are generally determined by the ASTM Standard Method of Test for Distillation of Creosote (D 246)[2] or by the similar standard method adopted by the American Wood-Preservers' Assn. These standards are recognized nationally as the methods to be used in establishing specification requirements for creosote and similar wood preservatives.

In these standard procedures the sample is distilled from a short-neck flask, with the bulb of the thermometer close to the liquid level. When complex mixtures of wide boiling range, such as creosote oil, are subjected to distillation in a flask having practically no provision for rectification, as is the case in the standard method, the lower boiling constituents to a considerable extent are held back by the higher boiling components and as the temperature rises are subsequently distilled over with higher boiling materials. This was demonstrated some 20 years ago by comparative distillation data obtained at the Forest Products Laboratory on a series of creosotes of varying boiling ranges, using the Hempel flask method and the standard method.[3]

Since the presence of low-boiling constituents is not properly reflected in the results of the standard test, this method is of doubtful value in research on creosote oils as used in wood preservation, particularly when studying changes in composition due to weathering in service or when correlating effectiveness of a preservative with its composition according to boiling ranges. Fractional distillation, which would give the desired information, requires a relatively large sample, rather elaborate apparatus, continuous and careful control, and is time consuming; for these reasons, it is not suitable for general use. The purpose of the work here reported was to develop a simple and rapid distillation test, primarily for use in research work on creosote oil, results of which would be in reasonably close agreement with those obtained by fractional distillation.

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13–18, 1954.

[1] Research Chemist, Barrett Div., Allied Chemical and Dye Corp., Edgewater, N. J.

[2] Standard Method of Test for Distillation of Creosote (D 246 - 49), 1952 Book of ASTM Standards, Part 4, p. 902.

[3] "Extract from the Report of Committee 4 on Preservatives," *Proceedings*, Am. Wood-Preservers' Assn., Vol., 28, pp. 38, 39, 47, 48, 65, and 66 (1932).

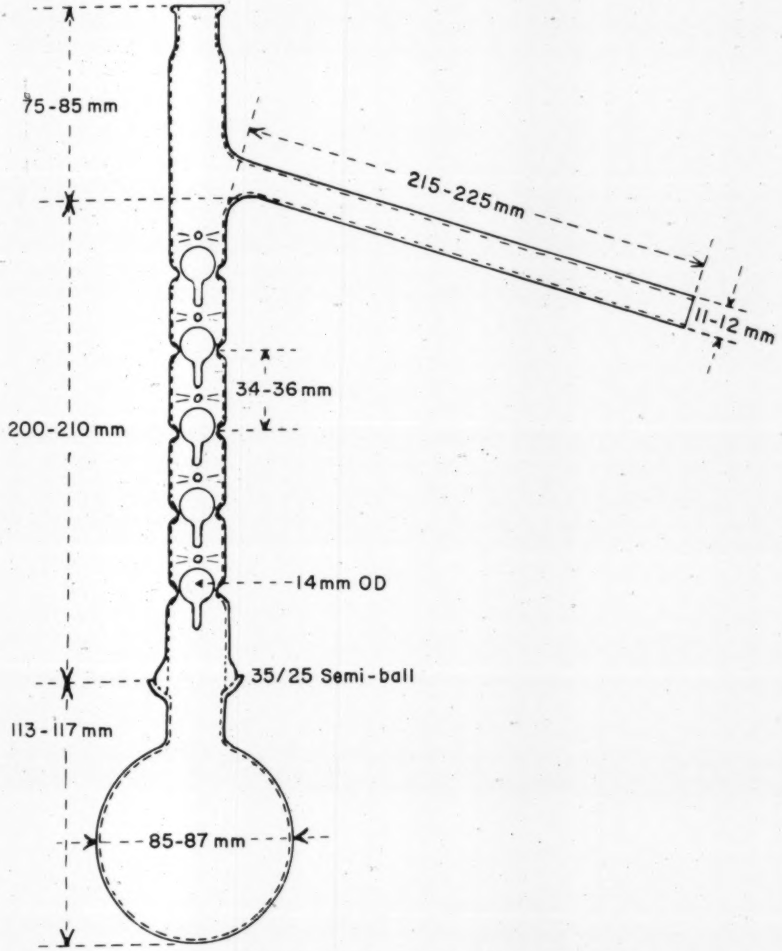

FIG. 1.—5-Ball Snyder Distillation Column and Flask.

SELECTION OF APPARATUS

The selection of suitable apparatus was influenced by considerations of size, simplicity, and ease of operation. A round-bottom flask of the same capacity (300 ml) used in ASTM Standard Method D 246 was selected so that samples of approximately 100 ml could be distilled without excessive foaming. To keep the column holdup to a minimum the use of a short column of the Snyder (ball) or Vigreaux type was indicated. A

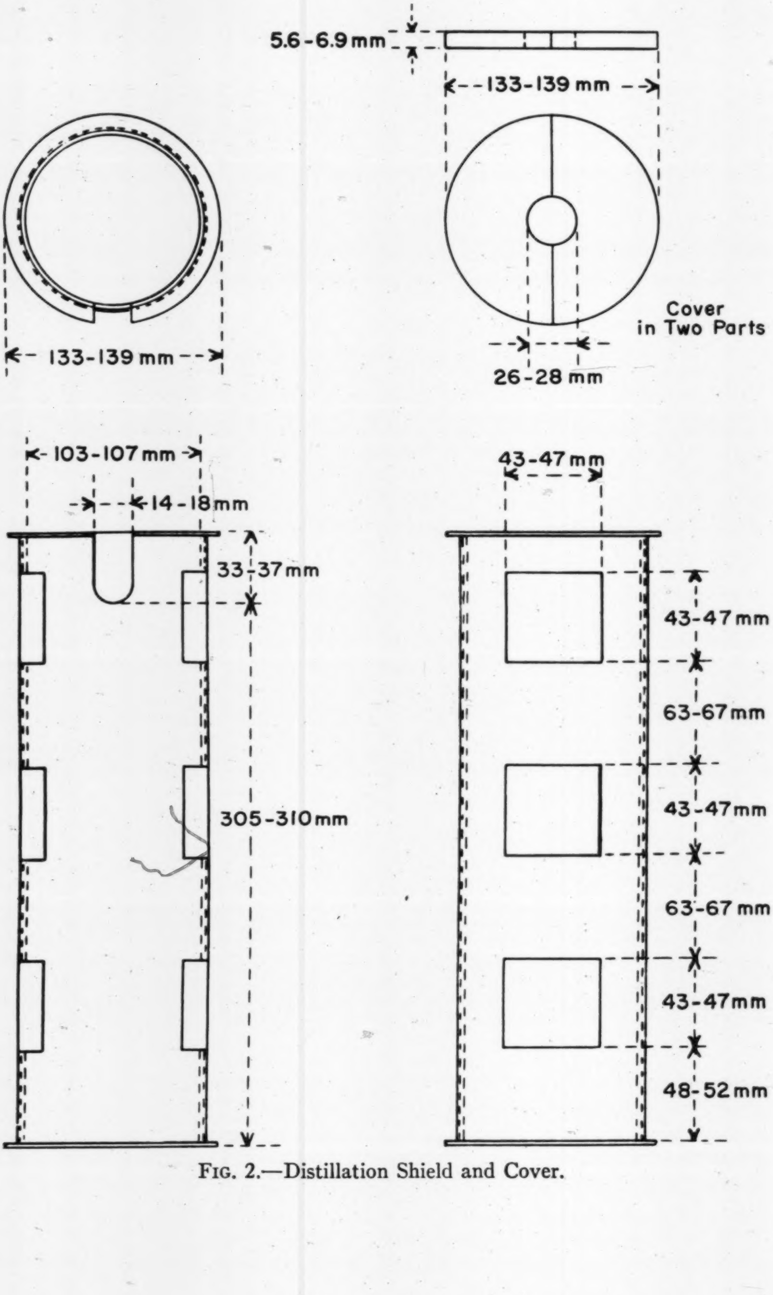
5.6-6.9 mm
133-139 mm
Cover in Two Parts
26-28 mm
133-139 mm
103-107 mm
14-18 mm
33-37 mm
305-310 mm
43-47 mm
43-47 mm
63-67 mm
43-47 mm
63-67 mm
43-47 mm
48-52 mm

FIG. 2.—Distillation Shield and Cover.

Snyder column, 25 mm in outside diameter, was chosen because previous experience in our laboratories had shown that a column of this type and diameter is efficient and suitable for the fractionation of creosote. In exploratory work Snyder columns with 10 balls and 5 balls were compared. A comparison of the 5-ball Snyder column and a Vigreaux column of the same length was also made, as will be described later. Considering efficiency of fractionation, holdup in the column, and simplicity of operation, a 5-ball section of Snyder column was decided upon, with semi-ball connections between column and flask, as shown in Fig. 1. The tubulature near the top of the column was of the same dimensions and was placed at the

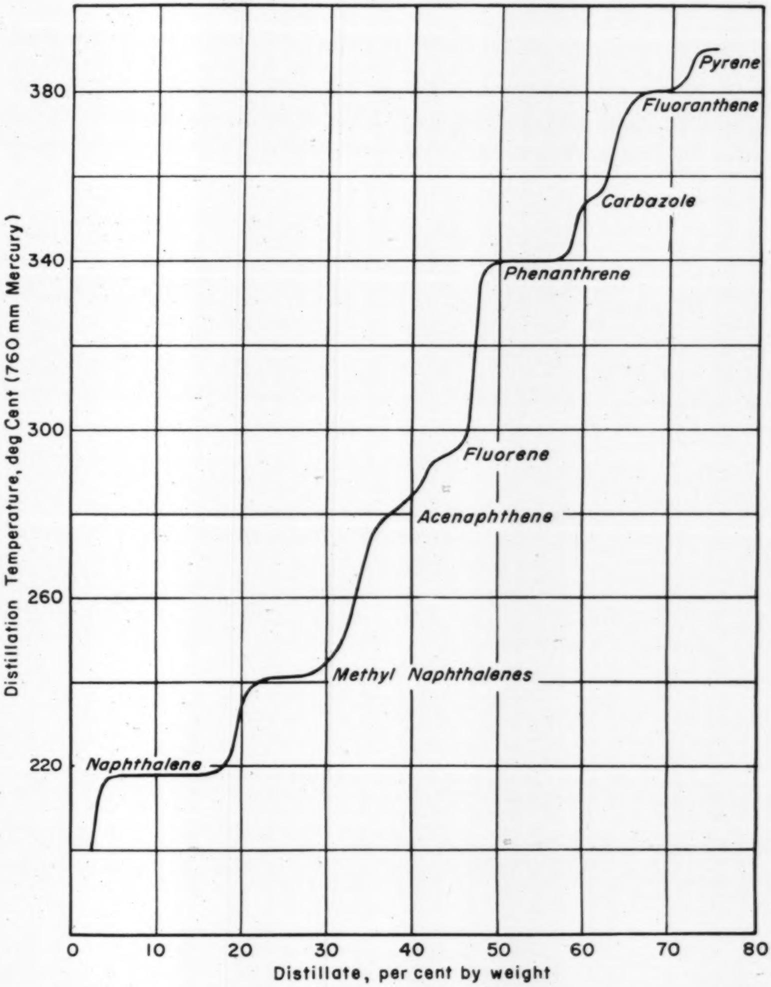

FIG. 3.—Fractionation Curve of Oil No. 16: Medium-Residue Creosote as Used for Brush Treatment.

same angle as the tubulature on the flask used in Method D 246. The height of the column to the tubulature was so selected initially that a shield of three stacked distillation shields, of the type specified in the standard method, could be used. As the work progressed, a suitable shield, dimensions of which are shown in Fig. 2, was constructed. The remainder of the apparatus, such as burner, burner shield, wire gauzes, thermometer, condenser, receivers, etc., was the same as specified in the ASTM standard method.

OPERATION

A study of fractionation graphs of creosote oils derived from coke-oven tar, a typical example of which is presented in Fig. 3, showed that steep rises between "flats" or "near-flats" occur at temperatures below 210 C and between 220 and 235 C, 250 and 275 C, and 300 and 330 C. It seemed reasonable that a short fractionating column would effect a fair degree of separation at temperatures within the range of these steep rises. The following temperatures as observed on the thermometer, without correction for emergent stem, were investigated as limiting temperatures for distillation fractions: 200, 210, 230, 235, 270, 300, 315, and 355 C. In other respects the distillations were carried out essentially as described in the ASTM standard method, except that the distillation rate was reduced from 80 to 100 drops per min to 35 to 45 drops per min. The 5-ball distillation test, as used in the work here reported, is presented in detail in the Appendix to this paper.

MATERIALS

For comparison of distillation test results with fractionation data ten creosote oils derived from coke-oven tar and one coke-oven tar were used. Nine of these creosotes and the tar are the same materials as have been used in a cooperative investigation of creosote, and details of their source and preparation as well as their physical properties have been described.[4] Three of the oils, Nos. 1, 2, and 3, were prepared directly from oils distilled commercially from coke-oven tar and are so-called "straight-run" creosotes of low, medium, and high distillation residue, respectively. Oils Nos. 4, 5, and 6 are medium-residue creosotes prepared from the same commercial oils, and typify creosotes low in tar acids, low in naphthalene, and low in tar acids and naphthalene, respectively. Similarly, oil No. 7 represents a low-residue creosote low in tar acids and naphthalene; and oil No. 8, a high-residue creosote low in tar acids and naphthalene. Oil No. 14 is a coke-oven tar, source of oils Nos. 1 to 8. Oil No. 10 is a low-residue English coke-oven tar creosote. Oil No. 16, not used in the cooperative program, is a medium-residue creosote as used for brush treatment. The fractionation curve of this creosote is shown in Fig. 3. Fractionation curves of the other creosotes and of the coal tar were presented at a meeting of the American Wood-Preservers' Assn.[5] as part of an investigation to determine true boiling characteristics and distribution of major constituents of the oils used in the cooperative project.

Oils Nos. 17 to 22 inclusive were used to compare distillation results, obtained by the standard and 5-ball column methods, on creosote oils stripped of the normally occurring, lower-boiling constituents. These oils were prepared from creosotes derived from coke-oven tar by distilling off the naphthalene fraction through an 8-ball Snyder column to a vapor temperature of about 230 C.

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[4] "Co-operative Creosote Tests," *Proceedings*, Am. Wood-Preservers' Assn., Vol. 46, p. 68 (1950).

[5] H. L. Stasse, "Fractional Distillation of Creosote and Composition of Preservatives Used in the Cooperative Creosote Program," *Proceedings*, Am. Wood-Preservers' Assn., Vol. 50, p. 13–37 (1954).

TABLE I.—COMPARISON BETWEEN FRACTIONAL DISTILLATION AND DISTILLATION TESTS BY THE STANDARD METHOD AND BY THE 5-BALL COLUMN METHOD.

	Oil No. 1			Oil No. 2			Oil No. 3			Oil No. 4			Oil No. 5			Oil No. 6		
	Standard	Fractionation	5-Ball Column	Standard	Fractionation	5-Ball Column	Standard	Fractionation	5-Ball Column	Standard	Fractionation	5-Ball Column	Standard	Fractionation	5-Ball Column	Standard	Fractionation	5-Ball Column
Distillate to 200 C, per cent by weight	...	5.0	4.6	...	4.0	2.0	...	2.5	2.1	...	2.5	1.5	...	4.5	3.9	...	4.0	3.6
Distillate to 210 C, per cent by weight	2.5	7.0	10.7	1.7	5.0	5.2	0.3	3.5	6.1	0.4	3.0	3.6	1.2	6.0	6.6	0.5	4.5	5.4
Distillate to 230 C, per cent by weight	...	38.0	39.8	...	31.0	30.9	...	18.0	18.5	...	23.0	22.9	...	19.5	20.4	...	18.0	18.5
Distillate to 235 C, per cent by weight	18.5	38.0	41.8	15.2	31.5	32.3	6.1	18.5	19.5	7.2	23.0	23.9	7.3	20.5	21.2	5.7	18.5	19.4
Distillate to 270 C, per cent by weight	45.8	46.0	47.2	37.2	38.0	38.2	18.6	23.0	22.9	26.0	28.5	29.4	22.9	27.5	27.7	21.8	25.5	26.7
Distillate to 300 C, per cent by weight	...	57.0	57.0	...	48.0	46.3	...	31.0	29.7	...	40.0	38.5	...	40.0	38.4	...	38.0	39.6
Distillate to 315 C, per cent by weight	59.9	58.0	61.0	50.1	49.0	49.9	30.7	32.0	34.5	40.1	42.5	42.5	40.6	41.5	42.9	39.1	39.0	43.7
Distillate to 355 C, per cent by weight	81.0	75.0	81.0	70.0	64.5	69.2	50.8	48.0	54.7	64.2	62.5	65.1	66.7	62.5	68.2	64.9	60.0	66.1
Distillate to 370 C, per cent by weight	...	78.0	...	...	68.0	...	...	53.0	...	...	65.0	...	...	66.0	...	...	63.0	...

	Oil No. 7			Oil No. 8			Oil No. 10			Oil No. 14			Oil No. 16		
	Standard	Fractionation	5-Ball Column	Standard	Fractionation	5-Ball Column	Standard	Fractionation	5-Ball Column	Standard	Fractionation	5-Ball Column	Standard	Fractionation	5-Ball Column
Distillate to 200 C, per cent by weight	...	4.5	3.5	...	2.5	2.9	...	4.5	3.8	...	2.5	2.0	...	2.0	1.5
Distillate to 210 C, per cent by weight	0.6	5.0	6.4	0.7	3.0	4.5	1.0	6.5	7.1	0.1	3.0	4.3	...	2.5	2.4
Distillate to 230 C, per cent by weight	...	23.5	22.8	...	12.5	12.0	...	23.0	23.7	...	15.5	16.1	...	19.5	21.6
Distillate to 235 C, per cent by weight	8.4	24.0	25.4	3.0	13.0	12.8	8.5	24.0	25.8	4.7	16.0	16.7	5.9	20.5	25.0
Distillate to 270 C, per cent by weight	30.1	32.5	33.6	10.5	17.0	17.3	33.1	36.0	38.0	13.7	18.5	19.8	31.1	35.0	36.0
Distillate to 300 C, per cent by weight	...	48.5	48.8	...	26.0	25.1	...	53.0	55.6	...	23.5	23.8	...	...	...
Distillate to 315 C, per cent by weight	51.4	49.0	52.4	23.5	27.0	28.1	58.9	56.0	61.1	22.1	24.5	27.1	46.9	47.5	49.5
Distillate to 355 C, per cent by weight	81.6	72.5	81.4	46.1	45.0	51.3	84.4	78.0	85.1	33.2	33.0	37.5	65.8	60.0	68.2
Distillate to 370 C, per cent by weight	...	75.0	...	...	48.0	...	...	83.0	...	...	35.0	...	...	64.0	...

Discussion of Results

Experimental data by the 5-ball Snyder column distillation test on ten samples of coke-oven tar creosote and one sample of coke-oven tar are tabulated in Table I together with corresponding distillation results by ASTM Standard Method D 246 and fractionation data. Except for fractionation data, temperatures shown are observed temperatures, uncorrected for emergent stem and barometric pressure, as is common practice in creosoters' distillation tests. When the temperatures refer to amounts of distillate by fractional distillation, they represent properly corrected temperatures. It is evident from a study of these data that quantities distilling to temperatures of 210 and 235 C, determined by the standard method, do not reflect the amounts actually distilling to these temperatures as determined by fractional distillation. At 270 C, results by the standard method are still lower than the amounts actually distilling to this temperature as determined by fractional distillation, in some cases materially so. At 315 C, agreement is generally better, but at 355 C the percentage of total distillate by the standard test is significantly higher than by fractionation. A comparison of results by the 5-ball column distillation test with fractionation data indicates good agreement at temperatures of 200, 230, 270, and 300 C. The 5-ball column distillation generally yields slightly, but significantly, larger quantities of distillate to 210, 235, and 315 C. This may be explained by the fact that the actual distilling temperatures with 5-ball column corresponding to these observed temperatures are too close to the plateaus of naphthalene (218 C), the methyl naphthalenes (240 to 245 C), and phenanthrene (340 C), respectively, to effect a satisfactory separation. Agreement at 355 C is poor, partly due to failure to apply the emergent stem correction, which amounts to approximately 15 C at this temperature. When the amount of distillate to 355 C is compared with the amount distilling to 370 C by fractionation, the agreement is still unsatisfactory, probably due to the chemical complexity of the high-boiling mixture.

Stripped Creosote Oils

During weathering, in specimens of wood treated with creosote preservatives, the lower-boiling constituents of creosote gradually vaporize and oils recovered from exposed specimens may no longer contain the lower-boiling constituents originally present in the creosote. To determine differences in results obtained by the standard method and the 5-ball column method, a number of coke-oven tar creosotes from which the front end had been stripped were subjected to distillation tests by the two procedures. Results of this work are tabulated in Table II. It is evident from these data that a much larger amount of lower-boiling distillate is shown by the 5-ball column distillation test, as is the case in the series of tests for Table I. However, in the testing of the normal creosote oils, agreement between the two methods was fairly satisfactory at 270 C, but with these stripped oils this temperature of agreement has now been raised to 315 C or higher. These results in particular stress the importance of using a fractional distillation test when characterizing creosote which has been subjected to simulated exposure or has been extracted from weathered specimens of treated wood or commercially treated timber.

Vigreaux Column

Since the Vigreaux type column is more readily available than the Snyder type, experiments on selected creosotes were carried out to determine whether

TABLE II.—COMPARISON BETWEEN DISTILLATION TESTS BY THE STANDARD METHOD AND BY THE 5-BALL COLUMN METHOD.

	Oil No. 17		Oil No. 18		Oil No. 1		Oil No. 20		Oil No. 21		Oil No. 22	
	Standard	5-Ball Column	Standard	5-Ball Column	Standard	B-5all Column	Standard	5-Ball Column	Standard	5-Ball Column	Standard	5-Ball Column
Distillate to 210 C, per cent by weight	None	None	None	0.3	None	None	None	0.4	None	None	None	None
Distillate to 230 C, per cent by weight	None	3.3	None	2.9	None	0.9	None	2.7	None	1.4	None	0.6
Distillate to 235 C, per cent by weight	None	...	None	...	None	...	None	...	None	...	None	...
Distillate to 270 C, per cent by weight	3.5	16.5	36.5	39.4	None	9.0	13.7	27.7	0.8	13.9	None	7.3
Distillate to 300 C, per cent by weight	...	33.2	...	54.1	...	28.4	...	48.3	...	33.6	...	25.3
Distillate to 315 C, per cent by weight	36.8	38.2	60.3	58.3	29.4	36.7	56.7	56.2	38.9	42.6	21.6	32.9
Distillate to 355 C, per cent by weight	67.0	66.6	77.3	77.6	64.9	68.3	82.8	81.5	73.7	73.3	67.7	71.0

TABLE III.—COMPARISON BETWEEN DISTILLATION TESTS BY THE 5-BALL COLUMN AND VIGREAUX COLUMN METHODS.

	Oil No. 1		Oil No. 2		Oil No. 3		Oil No. 6		Oil No. 8		Oil No. 10		Oil No. 17	
	Vigreaux	5-Ball Column	Vigreaux	5-Ball Column	Vigreaux	5-Ball Column	Vigreaux	5-Ball Column	Vigreaux	5-Ball Column	Vigreaux	5-Ball Column	Vigreaux	5-Ball Column
Distillate to 200 C, per cent by weight.....	1.8	4.6	1.7	2.0	0.7	2.1	1.7	3.6	1.4	2.9	2.2	3.8	None	
Distillate to 210 C, per cent by weight.....	8.6	10.7	5.5	5.2	2.8	6.1	4.2	5.4	2.7	4.5	3.9	7.1	0.4	None
Distillate to 230 C, per cent by weight.....	36.8	39.8	30.8	30.9	14.3	18.5	16.7	18.5	10.1	12.0	16.0	23.7	1.8	3.3
Distillate to 235 C, per cent by weight.....	38.7	41.8	33.9	32.3	16.4	19.5	19.0	19.4	12.5	12.8	19.4	25.8	2.1	3.8
Distillate to 270 C, per cent by weight.....	47.5	47.2	40.2	38.2	24.1	22.9	26.5	26.7	18.1	17.3	38.2	38.0	17.4	16.5
Distillate to 300 C, per cent by weight.....	56.5	57.0	46.3	46.3	29.8	29.7	36.4	39.6	22.6	25.1	53.1	55.6	32.3	33.2
Distillate to 315 C, per cent by weight.....	61.7	61.0	51.3	49.9	32.9	34.5	42.3	43.7	27.8	28.1	62.5	61.1	41.2	38.2
Distillate to 355 C, per cent by weight.....	82.9	81.0	72.4	69.2	54.9	54.7	68.0	66.1	53.9	51.3	83.5	85.1	70.1	66.6

the use of the ball-column was justified. The Vigreaux column used was of the same length as the 5-ball column and 20 mm in outside diameter. In other respects the apparatus and its operation were the same as used in the 5-ball column test. Results of these experiments are shown in Table III. More distillate to temperatures of 200 and 230 C is generally obtained by the 5-ball distillation, and the values also are in closer agreement with fractionation data than results by the Vigreaux column distillation test. In our opinion the difference in results at lower temperatures was sufficient to justify use of the Snyder column.

SIZE OF SAMPLE

Since it may be difficult at times to obtain 100 g of a sample for the distillation test, for instance, when recovering oil from treated wood which has been in service for a long period of time, the effect on distillation test results of a moderate reduction in size of sample was determined for one creosote. The test data, tabulated below, indicate that results are not significantly affected by a moderate reduction in weight of sample. Subsequent work has borne out this conclusion.

	Per cent by Weight	
	73-g Sample	100-g Sample
Total distillate to 210 C........	2.1	2.6
Total distillate to 230 C........	19.2	20.2
Total distillate to 270 C........	32.5	33.1
Total distillate to 315 C........	52.7	52.9
Total distillate to 355 C........	73.7	74.1

REPRODUCIBILITY

A thorough study of reproducibility of the 5-ball distillation test, which would require the cooperation of other laboratories on a series of tests designed for the purpose, has not been made. However, experience with the test procedure has shown that the reproducibility is of the same order as that of the standard method. To illustrate this, the following results were obtained by different operators on one sample of creosote:

	Per cent by Weight		
Operator	A	B	B
Total distillate to 200 C	5.1	4.2	4.6
Total distillate to 210 C	10.2	11.1	10.7
Total distillate to 230 C	40.9	39.2	39.3
Total distillate to 270 C	47.0	47.1	47.6
Total distillate to 300 C	56.4	57.6	57.1
Total distillate to 315 C	62.2	61.8	62.1
Total distillate to 355 C	79.4	80.9	82.8

CONCLUSION

In conclusion it may be stated:

1. Due to the fact that practically no rectification of distillate takes place in the standard distillation method, customarily used for the control of creosote, the relative amounts of lower-boiling constituents are not reflected in this test as they are in a fractional distillation.

2. The standard method is therefore not suitable for use in research studies of the composition of creosote according to boiling ranges or for determination of changes which take place on exposure and weathering in service.

3. A 5-ball column distillation test, which is a modification of the standard method and is described in detail in the Appendix, is a rapid method for obtaining distillation data reasonably concordant with results obtained by fractional distillation. It is particularly suggested for use in research studies of creosote.

Acknowledgment:

The author gratefully acknowledges the valuable assistance of H. S. Rodgers of the Barrett Division Research Laboratory, who carried out the major portion of the laboratory work.

APPENDIX

5-BALL COLUMN DISTILLATION TEST

Applications of Test:

1. This test is applicable to coal tars, creosote oils, carbolic oils, and other coal tar products, for the purpose of estimating the amounts of fractionated distillate to vapor temperatures of 200, 230, 270, and 300 C.

Apparatus:

2. The apparatus shall comprise the following:

(*a*) Fractionating column, 5-ball, "Pyrex" brand glass, 25 mm outside diameter with 35/25 inner semi-ball connection at lower end; shown in Fig. 1.

(*b*) Distilling flasks, "Pyrex" brand glass, round bottom, with 35/25 outer semi-ball connection in short neck; 300-ml capacity.

(*c*) Condenser tube, "Pyrex" brand glass, tapered, conforming to the following dimensions:

Outside diameter of small end	12.5 ± 1.5 mm
Outside diameter of large end	28.5 ± 3.0 mm
Length	360 ± 4 mm
Length of tapered part	100 ± 5 mm

(*d*) Flask shield, a galvanized iron shield made of 22 gage galvanized iron lined with $\frac{1}{8}$-in. asbestos, riveted to the metal; provided with a cover comprising two pieces of $\frac{1}{4}$-in. "Transite" board; and fitted with transparent windows as shown in Fig. 2.

(*e*) Gauze, two sheets of 20-mesh wire gauze made of No. 26 B and S gage "Nichrome" wire, and 125 to 150 mm in diameter or square.

(*f*) Burner shield, a cylindrical metal shield approximately 100 mm high, 95 to 105 mm in diameter, and having a peephole 25 mm in diameter centered about 32 mm below the ring support. The top of the shield shall be flanged to permit its being suspended from the ring support.

(*g*) Receivers, containers having a nominal capacity of 50 to 125 ml and tared to the nearest 0.05 g.

(*h*) Thermometer, −2 to 400 C, ASTM high distillation.

(*i*) Usual laboratory apparatus, as required.

Assembly of Apparatus:

3. Suspend the burner shield by its flange from the support ring, place the specified two sheets of wire gauze on the burner shield, and place the flask shield on the upper sheet of gauze. Insert the thermometer through a cork in the top of the 5-ball column so that the top of the thermometer bulb is level with the lowest point of juncture between the tubulature and the column, inside, and the stem is aligned on the axis of the column. Connect the 5-ball column to the distilling flask by means of a semi-ball clamp, using a heavy silicone grease to lubricate the semi-ball connections. Place the assembled column and flask in the flask shield with the bottom of the flask resting on the gauze, and connect the condenser tube to the tubulature of the column with a tight cork joint, having the tubulature project 30 to 50 mm through the cork. Support the condenser tube in a position such that it is in alignment with the tubulature of the flask, and the thermometer is vertical. Place the shield cover over the flask shield around the neck of the column.

TABLE IV.—ADJUSTMENT OF DISTILLATION TEST TEMPERATURES FOR BAROMETRIC PRESSURE.

Barometric Pressure, mm of mercury	Fractionation Temperatures for Various Barometric Pressure Ranges, deg Cent								
786 to 795	172	202	212	232	237	272	302	317	357
776 to 785	171	201	211	231	236	271	301	316	357
766 to 775	171	201	211	231	236	271	301	316	356
756 to 765	*170*	*200*	*210*	*230*	*235*	*270*	*300*	*315*	*355*
746 to 755	170	199	209	229	234	269	299	314	354
736 to 745	169	199	209	229	234	269	299	314	354
726 to 735	168	198	208	228	233	268	298	313	353
716 to 725	168	198	208	228	233	267	297	312	352
706 to 715	167	197	207	227	232	267	297	312	351
696 to 705	167	197	207	226	231	266	296	311	351
686 to 695	166	196	206	226	231	265	295	310	350
676 to 685	166	195	205	225	230	265	295	309	349
666 to 675	165	195	205	225	230	264	294	309	348
656 to 665	165	194	204	224	229	264	293	308	348
646 to 655	164	194	204	223	228	263	292	307	347
636 to 645	164	193	203	223	228	262	292	307	346
626 to 635	163	193	202	222	227	262	291	306	345
616 to 625	163	192	202	221	226	261	290	305	345
606 to 615	162	191	201	221	226	260	290	305	344
596 to 605	162	191	201	220	225	260	289	304	343

Preparation of the Sample:

4. (*a*) Thoroughly stir or otherwise mix the sample immediately before removing the portion for testing, warming if necessary to insure a complete mixture free from crystallized solids. Take care to avoid loss of volatile material.

(*b*) If the sample contains more than 1.0 per cent of water a representative portion shall be dehydrated before distillation in accordance with ASTM Method of Test for Water in Creosote (D 370 – 33).[6]

Procedure:

5. (*a*) Weigh the distilling flask to the nearest 0.1 g and weigh 100.0 ± 0.1 g of the sample into it. If insufficient material is available for a 100 g charge, the test may be carried out with not less than 60 g weighed to the nearest 0.05 g. Assemble the apparatus as described in 3.

(*b*) Apply heat to the flask by means of a Bunsen burner. When the condensate forms at the bottom of the column reduce the heat so that the ring of condensate continues to rise slowly at a uniform rate. Adjust the rate of distillation, and subsequently maintain that rate, so that from 35 to 45 drops per min fall from the end of the condenser. Warm the condenser tube whenever necessary to prevent accumulation of solid distillates in the tube.

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[6] 1952 Book of ASTM Standards, Part 4, p. 921.

(*c*) Collect the distillate fractions in tared receivers, changing receivers as the thermometer indicates the maximum temperature for each specified fraction. The following fractions shall be collected:

Up to 170 C
170 to 200 C
200 to 230 C
230 to 270 C
270 to 300 C
300 to 355 C

Fractions at other temperatures, such as 170 to 210 C, 210 to 230 C, 270 to 315 C, and 315 to 355 C, are sometimes required. Do not correct for emergent stem of the thermometer, but if the barometric pressure is not within the range 756 to 765 mm of mercury adjust the temperature according to Table IV.

(*d*) When the maximum temperature of 355 C is indicated by the thermometer, immediately remove the flame and the flask-shield cover. Drain any oil remaining in the condenser tube into the receiver containing the last fraction. Weigh the receivers containing the distillate fractions to the nearest 0.05 g and record the weight of each fraction. Should any of the fractions contain water, determine the water volume and calculate the net weight of oil distillate, assuming that 1 ml of water weighs 1 g.

Report:

6. Report the results of the distillation test as percentages, to the nearest 0.1 per cent, based on the weight of water-free material.

STUDY AND DEVELOPMENT OF METHODS FOR DETERMINING IN-PLACE DENSITIES OF COHESIONLESS SOILS*

BY DONALD F. GRIFFIN[1]

SYNOPSIS

The desirability of measuring in-place densities of cohesionless soils has been long recognized. Some methods for doing this have been in existence for a number of years; yet, there appears to be no information generally available concerning the accuracy and reliability of any method.

The present study was conducted under USN Bureau of Yards and Docks Contract NOy-73233, at the Engineering Research Center of the University of Southern California. The methods investigated included the following: plastic injection, wedge, tube, sand funnel, and rubber balloon. Ottawa 20–30 Sand[2] and graded Ottawa sand[3] were used as the testing media in the laboratory. Some field studies were also conducted on the beach at Point Mugu, Calif.

For each method, a plot of control densities *versus* per cent deviation of test densities (from control densities) showed a straight-line relationship. It is concluded that certain methods are more reliable than others and that each method has a different straight-line relationship for each different sand.

Each method investigated involved shearing action on the soil. This action had the usual effect of causing loose sands to contract and tight sands to expand. Field studies produced limited evidence that: (1) test boxes filled by nature give reliable and accurate in-place density measurements; and (2) apparent cohesion of natural water contents reduces the volume changes caused by shearing action.

At the moment we are far from having developed a method for measuring in-place densities of cohesionless soils with consistently high accuracy. This is especially true for methods involving shearing action on the soil.

Complete results of all tests by all methods are summarized in Table I. Details for a limited number of the test results are shown graphically in the various figures.

There may exist in various unpublished files information about the accuracy of some methods used to measure in-place densities of cohesionless soils. Reference to some existing methods is made in various technical publications, but a fairly exhaustive literature survey revealed no published research data on in-place density measurements of cohesionless soils.

In performing density tests, close observation was maintained at all times in order to detect any possible errors, and the results of all tests with known error in procedure were discarded. The results of tests without such known error were included even though in many instances the test values deviated considerably either from control values or from average values of group tests. There appears to be no tangible reason why deviations within groups of tests at a given density should have ranged so widely.

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13–18, 1954.

[1] Associate Professor of Civil Engineering, University of Southern California, Los Angeles, Calif.

[2] Standard Method of Test for Tensile Strength of Hydraulic-Cement Mortars (C 190 – 49), 1952 Book of ASTM Standards, Part 3, p. 167.

[3] Standard Method of Test for Compressive Strength of Hydraulic-Cement Mortars (C 109 – 52), 1952 Book of ASTM Standards, Part 3, p. 119.

CONTROL DENSITIES

In order to perform multiple tests at a given density, a large heavily reinforced marine plywood box was constructed, with interior dimensions of 3 by 3 ft in plan by 1 ft deep. The volume of the box was determined accurately by weighing it full of water at known temperature.

After considerable experimentation, five different methods were discovered to reproduce five different densities fairly consistently within the test box and these have been adopted as the control densities. A brief discussion of these methods follows:

Density, S.—A U. S. No. 10 sieve (2.000-mm opening) was held in one hand about 19 in. above the top of the test box. Sand was poured through the sieve as it was slowly moved over the top of the test box.

Density, F.—A 5-gal capacity liquid fuel funnel was suspended from the ceiling over the center of the test box with the small orifice, 1.3125 in. in diameter, about 8 in. above the top of the test box. The funnel was kept filled with sand as it was swung forth and back across the box in parallel paths.

Density, V.—The test box was first filled to overflowing by pouring sand into it from a gallon can. The stem of a concrete vibrator was then inserted vertically until its tip reached the bottom of the box, the insertions forming a grid pattern with spacings about 8 in. on centers. During the vibrating period additional sand was added in order to maintain the level of the sand above the top of the test box.

Density, R.—Sand was poured loosely into the test box in depth increments of 3 in. Each increment was rodded with a $\frac{3}{16}$-in. steel rod in a grid pattern about 2 in. on centers.

Density, P.—The test box was filled by pouring sand loosely into it from a gallon can.

In each case the box was filled to overflowing and the excess sand was struck off with a heavy steel straightedge. The relative density levels obtained are listed below in order of increasing densities for the two sands used in the laboratory:

Ottawa 20-30 sand:[2] *P, F, R, V, S.*

Graded Ottawa sand:[3] *P, F, S, R, V.*

Weight Measurements.—The 9-cu ft test box and contents were weighed on a 2000-lb capacity scale. It was possible to estimate the scale reading to a $\frac{1}{4}$ lb. Sand samples obtained during the testing procedures were weighed on a balance with a capacity of 20 kg and a sensitivity of 1 g, or on a balance with a capacity of 1600 g and a sensitivity of 0.1 g.

PLASTIC INJECTION METHOD

A brass syringe and two custom-made needles were employed to inject fluids into the sand. The needles were 8.375 in. long with outside diameters of 0.187 in.[4] Each needle had a pointed tip, and holes 0.0465 in. in diameter were drilled through the walls of the tube. One needle had 96 holes uniformly distributed around the tube over a distance of 6 in. along the tube. The other needles originally had 4 holes near the tip end of the tube; additional holes were added from time to time. The needles were attached to the Syringe by means of a rubber tube (Fig. 1).

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[4] Wall thickness: 0.040.

Several different types of fluids were injected into the sand in the test box with completely unsatisfactory results. These fluids included liquid plaster-of-Paris, molten paraffin, a mixture of molten petrolatum and paraffin, hot asphalt, and carbowax dissolved in alcohol. Liquid plastics requiring only catalytic agents to cause them to harden were more promising. A Laminac resin together with a catalyst consisting of methylethyl ketone peroxide and an accelerator consisting of cobalt naphthenate proved to be an excellent media for obtaining solid balls of sand. Considerable experimentation with these materials disclosed that the following quantities were suitable for use in either dry sand or wet sand with moisture contents up to nearly 6 per cent:

American Cyanamid Laminac Resin No. L-4128, 50 ml
Cobalt naphthenate (6 per cent cobalt concentration), 0.3 ml
Lupersol-DDM. 10 ml

From time to time additional holes were added to the original 4-hole needle until it had a maximum of 28 holes. Comparisons between this needle and the needle which originally had 96 holes indicated that the 28-hole needle was optimum for ease of injection and for accuracy of results obtained.

In order to determine the volume of the plastic-sand lumps, they were weighed in water. To improve the boundary conditions of the lumps and prevent water from entering into interior voids, the lumps were first given a thin coating of paraffin by dipping them into liquid paraffin. Any needle holes appearing at the surface of the lumps were plugged with paraffin. It was found unnecessary to correct either for the weight or volume of the paraffin coating. All lumps were of nearly the same volume; all paraffin coatings were thin and uniform, resulting in constant errors rather

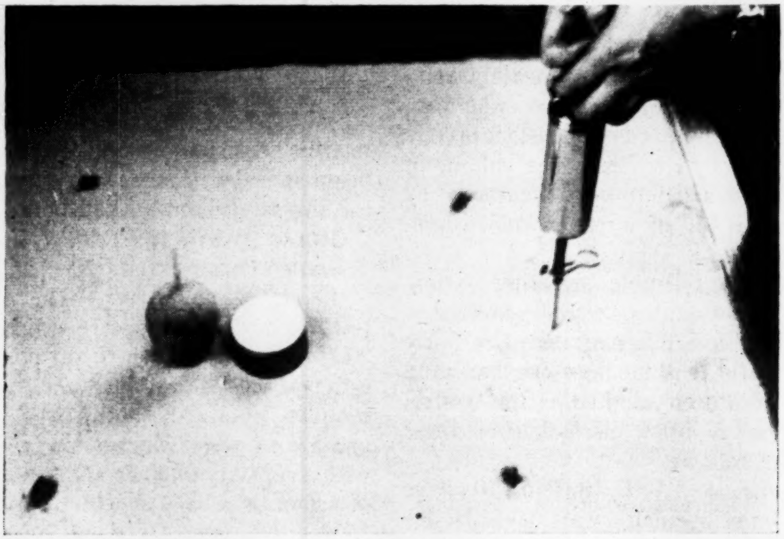


FIG. 1.—Plastic Injection Method. Injecting Plastic in 9-cu ft Container. Shown are a plastic-sand lump from a previous test and a tube with a plaster of Paris cap.

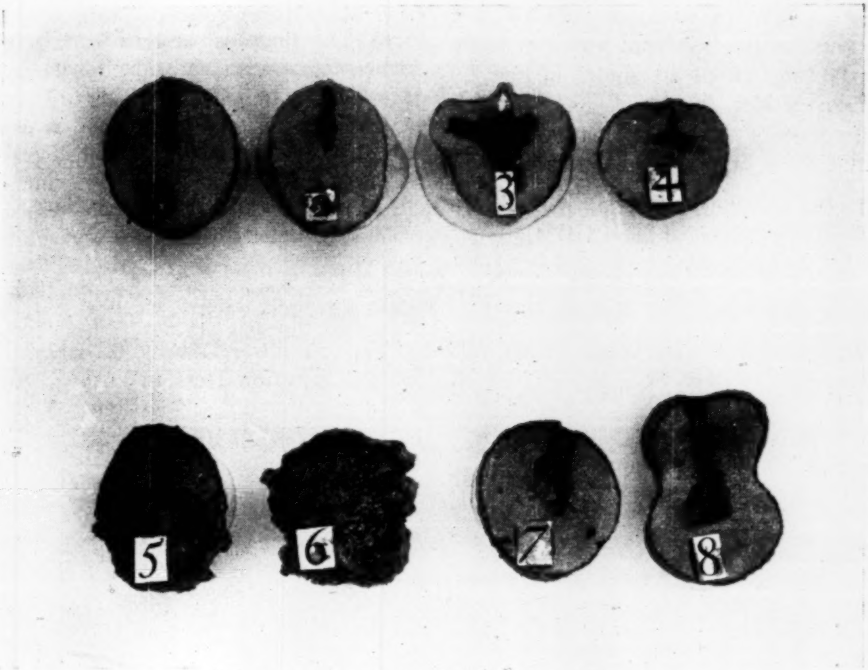


FIG. 2.—Sectional Views of Plastic-Sand Lumps.
Lumps 1 and 2: Ottawa 20-30 sand. Lumps 3 and 4: Graded Ottawa sand. Lumps 5 and 6: Point Mugu Beach sand. Lumps 7 and 8: Santa Monica Beach sand. Lump 3 is unusual with its large pocket of plastic.

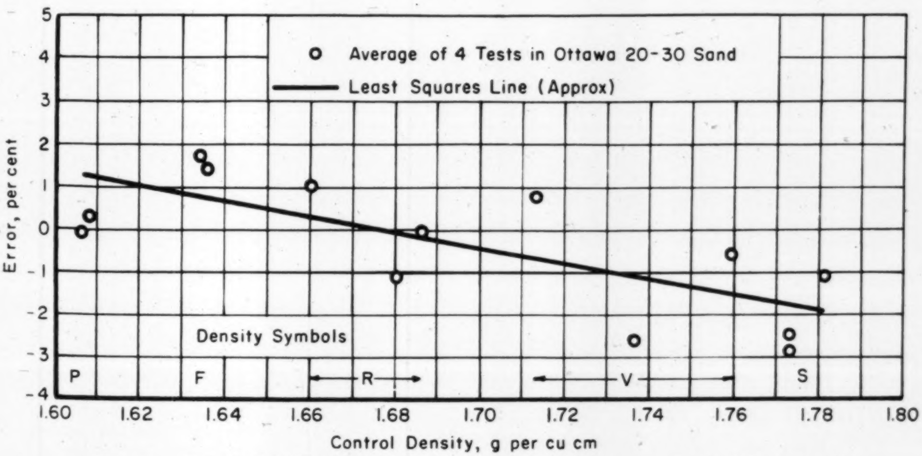


FIG. 3.—Plastic Injection Method. Test Density Error *versus* Control Density.

than differences in errors among the various lumps. Sectional views of some plastic sand lumps are shown in Fig. 2.

Density Test Procedure.—A simplified statement of general test procedure is outlined for liquid plastic injections:

1. The syringe is filled with the specified mixture of resin, cobalt, and DDM.
2. The syringe, fluid, needle, clamp, rubber tube are weighed.

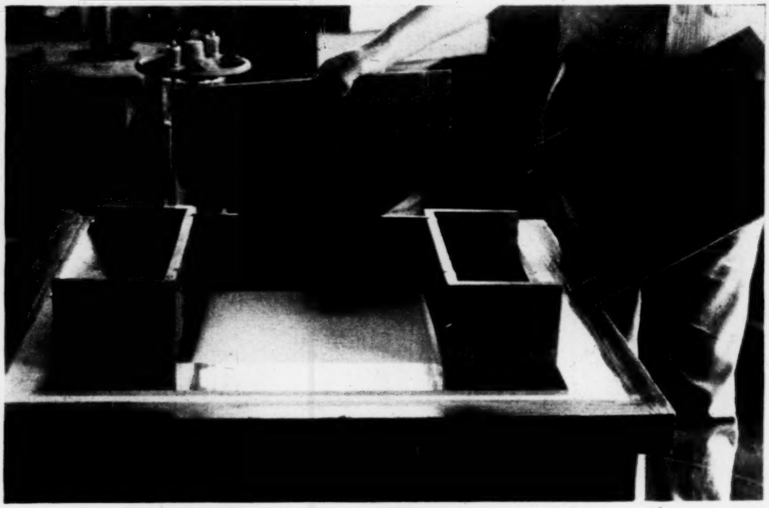


FIG. 4.—Apparatus for Wedge Method.

3. The needle is inserted into the sand to full length and the tube clamp is removed.
4. The fluid is injected slowly with constant pressure on the plunger of the syringe.
5. The tube clamp is replaced, the needle withdrawn, and the injector and residual fluid weighed.
6. The injector is cleaned in acetone before residual fluid congeals; curing time of plastics in air is about 6 min.
7. After the fluid congeals in the sand (allow 20 min for dry sand, and 1 hr for damp sand), plastic-sand lump is excavated.
8. A No. 24-gage brass wire is attached to the lump and the lump is dipped into melted paraffin heated to about 10 C above congealing temperature.
9. The lump is weighed in air.
10. The lump is weighed in water at known temperature, in order to determine its volume.

The measured density of sand is determined by deducting the amount of plastic in the lump from the weight of the lump in air and dividing the result by the displaced volume of water corrected for temperature:

$$\frac{\text{Weight of lump in air (item 9)} - \text{Weight of Plastic (item 5} - \text{item 2)}}{\text{Weight of lump in air (item 9)} - \text{Weight of lump in water (item 10)}}$$

Test Results.—Results of laboratory plastic injection tests in Ottawa 20-30 sand using the 28-hole needle are shown in Fig. 3. The per cent error is the difference between a density obtained by a test measurement and the control density, and this difference is divided by the control density and expressed as a per cent. A plus error indicates the density measured by a test method is greater than the control density, and a negative error indicates the density measured by a test method is less than the control density. Similar results were obtained with tests in graded Ottawa sand except that all errors were negative within the range of densities tested. The trend of plotted values sloped downward from left to right as in the case of the Ottawa 20-30 sand. These trends were concluded to be straight-line relationships as represented by least squares lines.

WEDGE METHOD

The wedge apparatus consisted of a supporting plate with guides attached, through which thin plates could be inserted to meet and form a wedge. The dimensions of the triangular cross-section of the wedge were 5.312 in. in height by 12.078 in. across the base. The wedge was 15.938 in. long and its volume was 8380 cu cm. A view of the wedge apparatus is shown in Fig. 4.

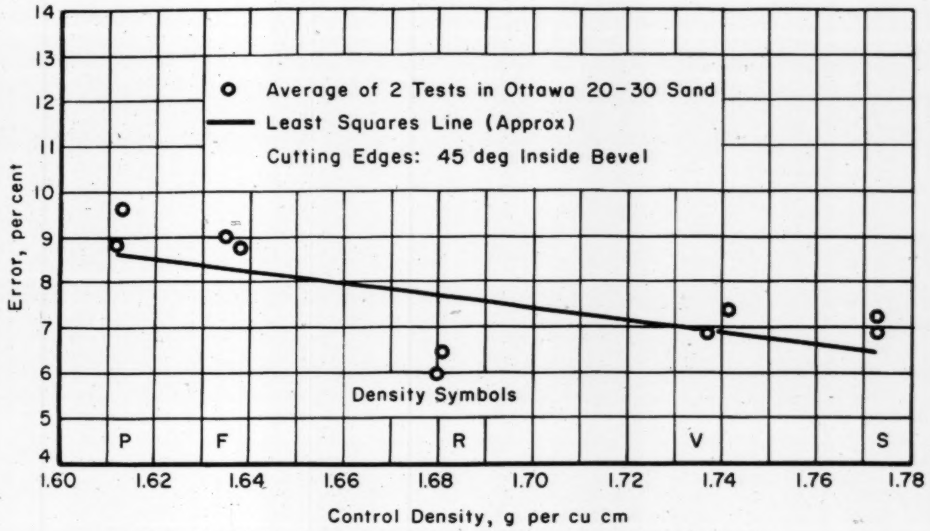


FIG. 5.—Wedge Method. Test Density Error *versus* Control Density.

Density Test Procedure.—The procedure for a test with the wedge apparatus is as follows:

1. The supporting plate is placed on leveled sand surface.
2. One of the rectangular plates is inserted until it extends beyond the apex of the wedge.
3. The second rectangular plate is inserted until it comes into contact with the first plate.
4. The vertical end plates are inserted until they come into contact with the sloping rectangular plates.
5. The sand is carefully excavated from the wedge and weighed.

The chief difficulty with the wedge is that close contact between the vertical and the sloping plates cannot be achieved because of interference of the sand particles. As a result some sand flows into the wedge cavity during excavation of the wedge sand. The amount of this sand has to be estimated visually as a known source of error.

Test Results.—Tests were made with wedge plates having various bevels on the cutting edges. Double bevels of 45 deg (central angle of 90 deg) and single bevels of 45 deg were used. The rectangular plates were 0.125 in. thick and the triangular plates 0.094 in. thick. Results are shown in Fig. 5 for tests in Ottawa 20-30 sand with a 45 deg inside bevel on the cutting edges of the plates. For other bevel arrangements on the cutting edges of the plates, the trends of error *versus* control densities roughly paralleled the one shown in Fig. 5.

The same type of results were obtained with the wedge as were obtained with the plastic injections.

TUBE METHOD

The tube method of determining in-place densities of cohesionless soils consists of inserting into the soil a cylindrical tube with open ends, capping the exposed end, and then carefully inverting the tube with contents. Figure 1 illustrates a tube inserted in sand and capped with plaster of Paris. All tubes were of seamless brass, $\frac{1}{16}$ in. in wall thickness, of both 3 in. and 5 in. in outside diameter and of different lengths and with different cutting edges.

Density Test Procedure.—Steps used in the procedure for determining densities by the tube method included:

1. The tube is pressed into the sand at a uniform rate until the sand reaches a predetermined mark on the tube, giving approximately the same depth of penetration for a given tube each time.

2. A thin flexible wax paper disk, of the same diameter as the inside diameter of the tube, is placed on the surface of the sand inside the tube to prevent loss of free moisture from the plaster of Paris into the sand.

3. Fluid plaster of Paris is poured uniformly over the disk to about $\frac{1}{4}$ in. thickness, but not projecting above the top of the tube.

4. After the plaster of Paris hardens, the sand is carefully excavated from around the outside of the tube to a mark around the tube 1.5 in. from the bottom to prevent exposing the lower end of the tube inadvertently.

5. A slightly concave dish or pan is slipped beneath the lower end of the tube with an arcing movement, the tube and dish inverted together and the surplus sand struck off with a straightedge.

6. The capped tube is weighed, first with sand, again without sand and again when filled with water at known temperature.

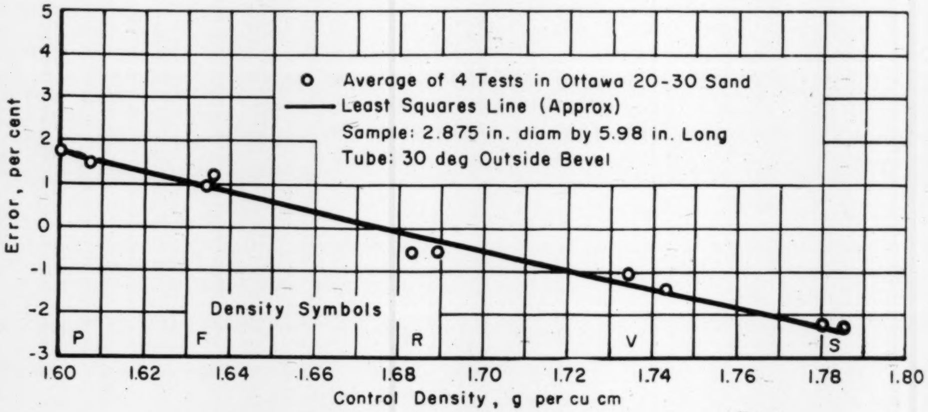


FIG. 6.—Tube Method. Test Density Error *versus* Control Density.

Test Results.—The types of cutting edges on the various tubes included 30-deg outside bevels, 30-deg inside bevels, 30-deg double bevels, 45-deg inside bevel, 45-deg outside bevels, and a semi-circular edge. The lengths of samples obtained with the various tubes ranged from approximately 1.5 to 6.5 in.

Results of tests in Ottawa 20-30 sand are presented in Fig. 6 as error in per cent *versus* control densities for the smaller diameter tube with an average sample length of 5.98 in. Results for the other tubes in both sands were similar, but the position of the trend line in each case was different.

SAND FUNNEL METHOD

Sand funnels have been used for a number of years in the determination of soil densities, but there is no published information regarding the accuracy of their results. In order to obtain a reasonably large size sample of sand for a density test a large sand funnel was designed (Fig. 7). The funnel had a lower cone with a maximum inside diameter of 12 in., a minimum inside diameter of 0.483 in., and a slope of 1.5 vertically to 1 horizontally. The upper part of the apparatus consisted of an inverted cone with the same side slopes and minimum inside diameter as the lower cone. Its maximum inside diameter at the top was 8 in., where a cylinder 6 in. long was attached. The top end of the cylinder was open and a U.S. standard sieve just fit into the opening. A plate in the form of an annulus was used to support the funnel on the surface of the sand to be tested.

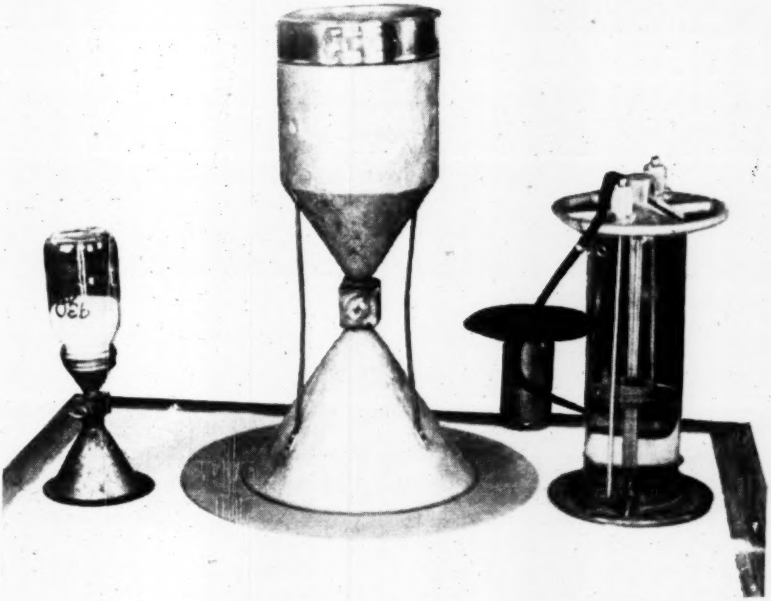


FIG. 7.—Left to Right: Small Sand Funnel on Supporting Plate with Tube, Large Sand Funnel on Supporting Plate, Tube with Supporting Plate Attached for Rubber Balloon Apparatus.

Calibration Procedure.—To determine the volume of material excavated in a density test, the amount and density of sand from the funnel required to fill the excavated cavity must be known. In a density test, the annulus is set on a level surface of the soil and sand is excavated through the hole in the annulus. In cohesionless material, this excavation will assume the shape of an inverted cone with its maximum diameter equal to that of the inside diameter of the annulus. The average of measurements of several cones thus formed gave a maximum diameter of 12.375 in. and a height of 3.10 in. A cone this size was constructed of aluminum and the density of sand required to fill this cone from the sand funnel was determined as follows:

1. The calibration cone is leveled on a table.

2. The supporting annulus is centered over the inverted calibration cone.

3. The funnel is centered over the supporting annulus with the valve closed.

4. 19,500 g of Ottawa 20–30 sand is weighed out.

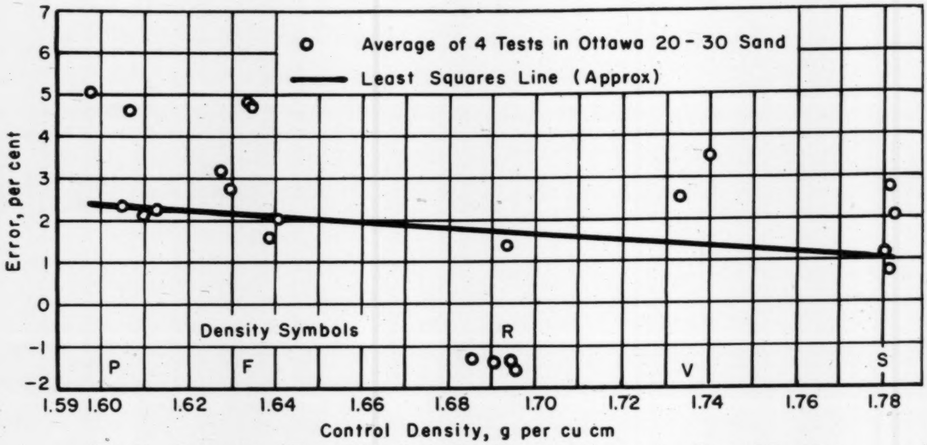


FIG. 8.—Large Sand Funnel Method. Test Density Error *versus* Control Density.

5. A U. S. No. 10 sieve is set over the top opening of the sand funnel.

6. The upper cone and cylinder are filled with sand to a level above the surface of the screen in the sieve.

7. The valve is opened to allow sand to fall into the calibration cone.

8. The elevation of the sand above the screen is maintained to a maximum until the supply of sand is exhausted.

9. Timing with a stop watch is begun immediately after the apparent downward motion of the sand has stopped. Usually there will follow an apparent upward motion of the sand. At the end of 60 sec close the valve. (Shorter time intervals gave erratic results.)

10. The sand remaining in the upper cone of the sand funnel is weighed.

11. The surface of the sand is leveled on the calibration cone and the sand remaining in the cone is weighed.

Calibration Results.—The average density of the sand in the calibration cone was found to be 1.562 g per cu cm. The probable error of this value for 39 tests was calculated to be ±0.05 × 1 per cent.

Density Test Procedure.—The procedure for a density test is identical with that used for a calibration test with the exceptions of items 1, 2, and 11. The first step is to place the supporting plate on a leveled sand surface and then carefully excavate and weigh the sand the density of which is to be tested. Next, the funnel is placed on the supporting plate and the above outlined procedure is continued. Item 11, of course, is omitted.

A supporting plate made of glass was first used in order to observe the effect of excavating under the inner circumference of the plate. It was observed that even slight cavities under the plate adjacent to the inner circumference did not fill with sand from the funnel.

The volume of the sand tested is determined by first deducting from the weight of total sand originally weighed out from the funnel, the weight of sand remaining in the upper cone of the funnel plus the weight of sand in the annulus opening plus the weight of sand in the lower cone of the funnel.

$$V = \frac{F_1 - F_2 - (A + C)}{\gamma}$$

where:

V = volume of excavated cavity,

F_1 = weight of sand weighed out for funnel,

F_2 = weight of sand remaining in funnel,

$A + C$ = weight of sand in annulus and in funnel cone above annulus, and

γ = density of sand in calibration cone.

The items A and C constitute a constant determined in the calibration tests. The remaining weight of sand is the amount filling the excavated cavity, and its volume is determined by dividing the weight by the density factor determined in the calibration tests. The density of the sand excavated from the cavity is determined by dividing its weight by the volume of the sand filling the cavity from the sand funnel.

Test Results.—Results of tests are shown in Fig. 8 as per cent error *versus* control density for tests in Ottawa 20-30 sand. No tests were performed with this apparatus in graded Ottawa sand.

LARGE SAND FUNNEL-TUBE METHOD

The sand funnel-tube method is identical with that of the sand funnel method except that a tube with a supporting annular plate attached was used with the funnel. The tube was 11.875 in. in inside diameter by 4 in. long with a 30-deg outside bevel on the cutting edge and a wall thickness of 0.077 in. On one end of the tube there was attached a supporting plate in the form of an annulus 19 in. in outside diameter by 0.1293 in. thick. In Fig. 7 the sand funnel is shown resting on the supporting annulus.

Calibration Procedure.—The calibration procedure used for the sand funnel was also used with the sand funnel-tube except that the tube with attached annulus replaced the calibration cone and the separate supporting plate. A tight-fitting disk sealed the bottom of the tube during calibration tests. About 26,500 g of Ottawa 20-30 sand or 21,600 g of graded Ottawa sand were used per test.

Calibration Results.—For 20 tests the average density factor of sand falling into the tube and the probable error of this value for each of the two sands was calculated to be:

Sand	Density, g per cu cm	Probable Error, per cent
Ottawa 20-30 sand	1.582	0.02 × 1
Graded Ottawa sand	1.520	0.04 × 1

The volume of the tube within the annulus was determined by weighing the above-mentioned disk of the same thickness as the supporting annulus in air and again in water.

Density Test Procedure.—The procedure for a density test is identical with that of a calibration test except that the tube is first inserted into the sand. Sand inside the tube is carefully excavated to a line drawn around the inside of the tube near the bottom. In this way approximately the same volume of sand is excavated each time. The surface of sand in the tube is left as a horizontal plane after excavation is completed.

Test Results.—Results of tests both in Ottawa 20-30 sand and in graded Ottawa sand are presented in Fig. 9, as per cent error *versus* control density. This figure illustrates clearly the differences in error for the two sands. In each case, the same kind of sand was used in the funnel as was used in the test box.

SMALL SAND FUNNEL-TUBE METHOD

The small sand funnel-tube has a funnel cone with maximum inside diameter of 4.75 in. and a slope of 1 horizontally to 1.732 vertically. The small end of the funnel had an opening of approximately 0.5 in. A quart jar was attached to the funnel. The tube used with the funnel was a 3-in. inside diameter seamless brass tube 1.652 in. long with a 30-deg outside bevel on the cutting edge. The wall thickness was 0.048 in. There was a 6-in. diam supporting plate 0.1435 in. thick attached to one end of the tube. The small sand funnel-tube apparatus is shown in Fig. 7.

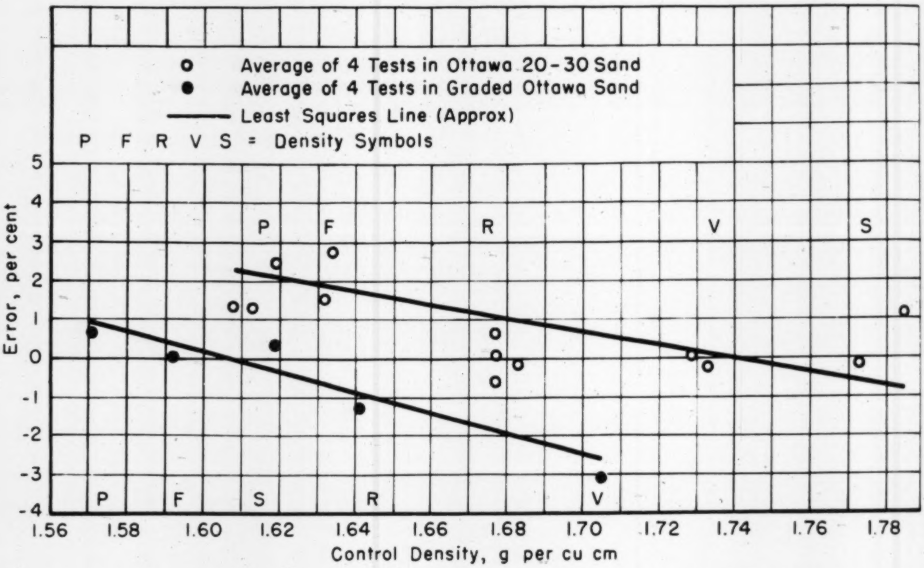


FIG. 9.—Large Sand Funnel-Tube Method. Test Density Error *versus* Control Density.

Calibration Procedure.—The calibration procedure was similar to that for the large sand funnel-tube. Steps required for determination of the density factor are:

1. The sand jar is filled with 1587 g of Ottawa 20–30 sand or graded Ottawa sand. This weight of sand nearly fills the jar and the same weight should be used each time.
2. The funnel is placed on the supporting annulus of the tube with a disk in place at the lower end of the tube.
3. The valve is opened and left open for 10 sec after the apparent downward motion of the sand has stopped. The apparent upward motion of the sand observed in the large sand funnel may also be observed here.
4. The valve is closed and the apparatus and residual sand are removed and weighed.
5. The sand is carefully leveled to the top of the supporting annulus on the tube with a straightedge.
6. The sand in the tube is weighed.

Calibration Results.—The density factor and the probable error of this value are shown below for each of the two sands tested.

Sand	Density, g per cu cm	Probable Error, per cent
Ottawa 20-30 sand.........	1.631	0.06 × 1
Graded Ottawa sand.......	1.542	0.10 × 1

Density Test Procedure.—The procedure for a density test is the same as for that used with the large sand funnel-tube. The amount of sand used in the small funnel is the same as that required for a calibration test for the small sand funnel-tube.

Test Results.—Results in both the Ottawa 20-30 sand and in the graded Ottawa sand are presented as per cent error *versus* control density in Fig. 10. The small sand funnel showed quite large variations in per cent error in Ottawa 20-30 sand as compared to the other methods. Also the differences in positions of the least squares lines for the two sands were most pronounced for this method.

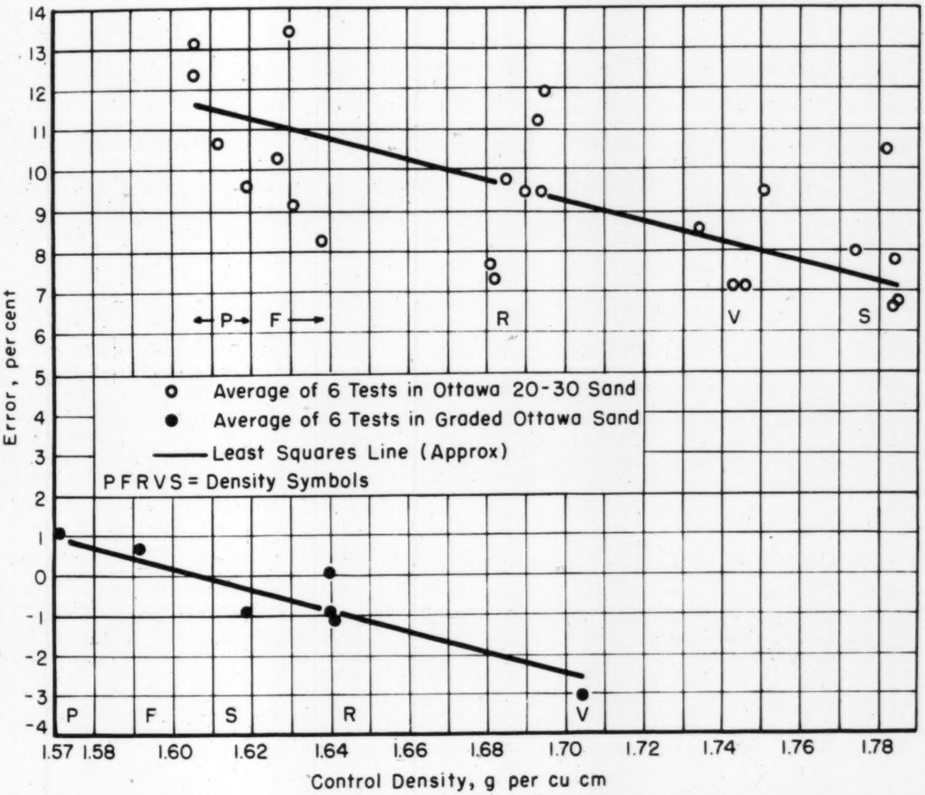


FIG. 10.—Small Sand Funnel-Tube Method. Test Density Error *versus* Control Density.

RUBBER BALLOON - TUBE METHOD

The rubber balloon-tube equipment consisted of a Rainhart rubber balloon apparatus and a tube attached to a supporting plate (Fig. 7). To determine the optimum size and volume of tube for best accuracy in volume determinations, experiments were made using glass tubes of various diameters and lengths. The tubes were closed at one end except for a pin hole through which air could escape when the balloon was expanded into the tube. These holes were plugged with wax in order to determine their true volume by filling them with water at known temperature. Two sizes of tubes that gave best results were 2.875-in. ID by 6 in. long and 4.875-in. ID by 6 in. long. Both tubes were of seamless brass with a wall thickness of the $\frac{1}{16}$-in. and with 30 deg outside bevels, and each tube had a supporting plate 8 in. in diameter by 0.126 in. thick.

TABLE I.—COMPARISON

Method	Deviation Band Width, per cent	Critical Density, g per cu cm	Average Sample, vol. cu cm	Density Equations[a]
RESULTS OF VARIOUS TEST METHODS WITH OTTAWA 20-30 SAND				
Plastic injection[b]	3.0	1.678	140	$\gamma = 1.50\,\gamma_m - 0.837$
Wedge				
45-deg inside bevel[c]	2.1		8380	$\gamma = 1.20\,\gamma_m - 0.490$
45-deg double bevel	1.2		8380	$\gamma = 1.43\,\gamma_m - 0.835$
45-deg outside bevel	2.9	1.633	8380	$\gamma = 2.00\,\gamma_m - 1.631$
Tubes: 30-deg outside bevel				
2.875-in. ID	5.3	1.658	155	$\gamma = 2.80\,\gamma_m - 2.983$
2.875-in. ID	1.9	1.668	439	$\gamma = 2.25\,\gamma_m - 2.083$
2.875-in. ID[d]	0.6	1.675	637	$\gamma = 1.58\,\gamma_m - 0.971$
4.875-in. ID	3.0	1.678	1811	$\gamma = 1.56\,\gamma_m - 0.939$
Tubes: 30-deg double bevel				
2.875-in. ID	1.3	1.675	472	$\gamma = 2.50\,\gamma_m - 2.512$
2.875-in. ID	1.0	1.673	670	$\gamma = 1.88\,\gamma_m - 1.472$
4.875-in. ID	2.5	1.674	1908	$\gamma = 1.74\,\gamma_m - 1.239$
Tubes- 30-deg inside bevel				
2.875-in. ID	1.1	1.657	450	$\gamma = 4.00\,\gamma_m - 4.965$
2.875-in. ID	1.3	1.641	631	$\gamma = 3.00\,\gamma_m - 3.277$
4.875-in. ID	1.7	1.674	1992	$\gamma = 2.05\,\gamma_m - 1.755$
Tubes: 45-deg inside bevel				
2.875-in. ID	0.6	1.650	475	$\gamma = 3.84\,\gamma_m - 4.682$
2.875-in. ID	2.0	1.637	590	$\gamma = 3.00\,\gamma_m - 3.273$
4.875-in. ID	1.0	1.685	1901	$\gamma = 2.21\,\gamma_m - 2.032$
Tubes: 45-deg outside bevel				
2.875-in. ID	2.1	1.670	449	$\gamma = 1.77\,\gamma_m - 1.286$
2.875-in. ID	2.3	1.663	628	$\gamma = 1.46\,\gamma_m - 0.762$
4.875-in. ID	1.9	1.680	1818	$\gamma = 1.87\,\gamma_m - 1.464$
Tubes: semicircular edge				
2.875-in. ID	1.4	1.675	479	$\gamma = 2.09\,\gamma_m - 1.821$
2.875-in. ID	0.5	1.665	650	$\gamma = 1.76\,\gamma_m - 1.265$
4.875-in. ID	1.5	1.660	1899	$\gamma = 1.54\,\gamma_m - 0.894$
Large sand funnel[e]	6.1		2126	$\gamma = 1.13\,\gamma_m - 0.259$
Large sand funnel-tube[f]	3.7	1.736	6748	$\gamma = 1.38\,\gamma_m - 0.660$
Small sand funnel-tube[g]	5.9		158	$\gamma = 1.25\,\gamma_m - 0.620$
Rubber ballon-tube				
2.875-in. ID x 6-in tube[h]	2.2		554	$\gamma = 1.12\,\gamma_m - 0.261$
4.875-in. ID x 6-in. tube	2.9		1613	$\gamma = 1.11\,\gamma_m - 0.253$

[a] γ_m = density measured by test method.
γ = corrected density (or laboratory control density).

[b] Fig. 3. Ottawa 20-30 Sand.

[c] Fig. 5. Ottawa 20-30 Sand.

[d] Fig. 6. Ottawa 20-30 Sand.

[e] Fig. 8. Ottawa 20-30 Sand.

[f] Fig. 9. Both Sands.

[g] Fig. 10. Both Sands.

[h] Fig. 11. Both Sands.

OF TEST METHODS.

Deviation Band Width, per cent	Critical Density, g per cu cm	Average Sample, vol. cu cm	Density Equations[a]
RESULTS OF VARIOUS TEST METHODS WITH GRADED OTTAWA SAND			
4.6		134	$\gamma = 1.16\,\gamma_m - 0.200$
3.5	1.604	8380	$\gamma = 2.66\,\gamma_m - 2.661$
3.3	1.610	150	$\gamma = 3.61\,\gamma_m - 4.201$
0.9	1.618	411	$\gamma = 1.77\,\gamma_m - 1.245$
2.5	1.615	613	$\gamma = 1.50\,\gamma_m - 0.809$
1.6	1.635	1838	$\gamma = 1.64\,\gamma_m - 1.047$
2.1	1.622	422	$\gamma = 1.76\,\gamma_m - 1.233$
3.2	1.622	613	$\gamma = 1.94\,\gamma_m - 1.524$
0.8	1.642	1828	$\gamma = 1.79\,\gamma_m - 1.296$
1.0	1.606	6748	$\gamma = 1.87\,\gamma_m - 1.396$
1.7	1.613	155	$\gamma = 2.08\,\gamma_m - 1.735$
1.9		559	$\gamma = 1.20\,\gamma_m - 0.424$
3.4		1566	$\gamma = 1.22\,\gamma_m - 0.451$

Density Test Procedure.—Before performing a density test, the rubber balloon was expanded into a 6-in. diameter by 4 in. long glass tube to see if the balloon expanded satisfactorily. The procedure used for a density test is as follows:

1. The assembled rubber balloon apparatus is set on a flat surface and an initial volume reading is taken with the balloon drawn up inside the water chamber. It should be made certain that all air is expelled from the balloon and that there are no folds in the balloon between the supporting surface and the apparatus.

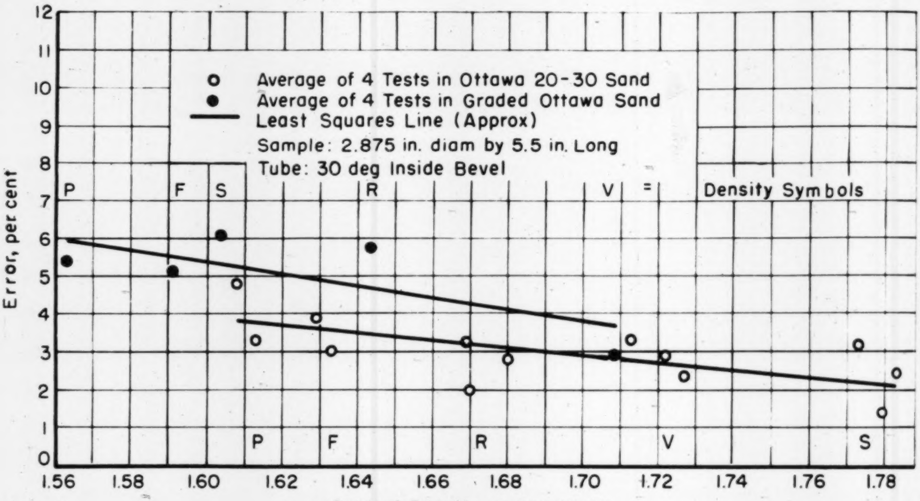


FIG. 11.—Rubber Balloon-Tube Method. Test Density Error *versus* Control Density.

2. A tube is inserted into the sand until the lower surface of the supporting plate rests on the surface of the sand. Sand from the inside of the tube is removed with a scoop to a mark about $\frac{1}{4}$ in. from the bottom of the tube. The sand is weighed.

3. The rubber balloon apparatus is set on the supporting plate of the tube. The balloon is expanded into the tube and a reading for volume is taken.

Test Results.—Test results for both of the Ottawa sands are presented in Fig. 11 as per cent error *versus* control density. This method gave slightly more consistent results with less variation in per cent error than other methods.

COMPARISON OF LABORATORY RESULTS OF TEST METHODS

In Table I are summarized the data relevant to a comparison of the various density-testing methods. All density-testing methods involved a shearing action on the soil and had the usual effect of causing loose sands to contract and tight sands to expand. Without exception, the results for every method tested showed an algebraic decrease in per cent deviation *versus* increasing control densities. At the critical density there is no error in measurement; however for some density-testing methods no critical density was observed within the range of densities tested.

All methods tested require the use of correction equations in order to adjust measured density values more closely toward true values. The correction equations were concluded to express straight-line relationships between measured density and control density or between per cent error and control density. Approximate least squares lines obtained from plotting measured densities *versus* control densities were used to determine the equations.

The magnitude of the adjustment of values by the equations is not necessarily a criterion of accuracy of a density-testing method. Rather, the width of the band of error of average measured values is the criterion of accuracy for a density-testing method. Individual test values at a given density are considered unreliable. A minimum of four tests at a given density should be the basis for determining average values. Deviation among such average values is generally less than the deviation among individual values. With the exception of the wedge method, a minimum of four tests at a given control density were used to establish average values for a given test method. (The wedge was too large to permit more than two tests to be made at one time in the test box.)

There appears to be no direct correlation between the ranges of error and the volume of samples obtained by the various methods, although the methods involving the smallest samples did not appear to give good results. In general, the ranges of error were less in the graded Ottawa sand than in the Ottawa 20-30 sand. In view of the fact that most natural sand deposits are graded, results in the graded Ottawa sand may be the more important. In fairness it must be pointed out that fewer tests were performed in the graded Ottawa sand. The results rather conclusively show that the two sands are quite different with reference to the position and slope of the least squares lines of per cent error *versus* control density for a given test method.

Of the density-testing methods investigated, one of the more feasible methods for field use appears to be the tube method. A sample size ranging from 3 to 4 in. in diameter by 5 to 6 in. long is recommended. Another method deemed feasible for field use is the rubber balloon-tube method with either a 3 or 5 in. diameter tube by 6 in. long.

The wedge method is not recommended because of definite interference between sand particles and plate intersections. The personal error would be too variable. The plastic injection method has a distinct advantage in that it can provide comparatively undisturbed samples for grain relationship study. It also has possibilities for use in connection with determination of in-place densities of coarse aggregates such as highway or runway base courses.

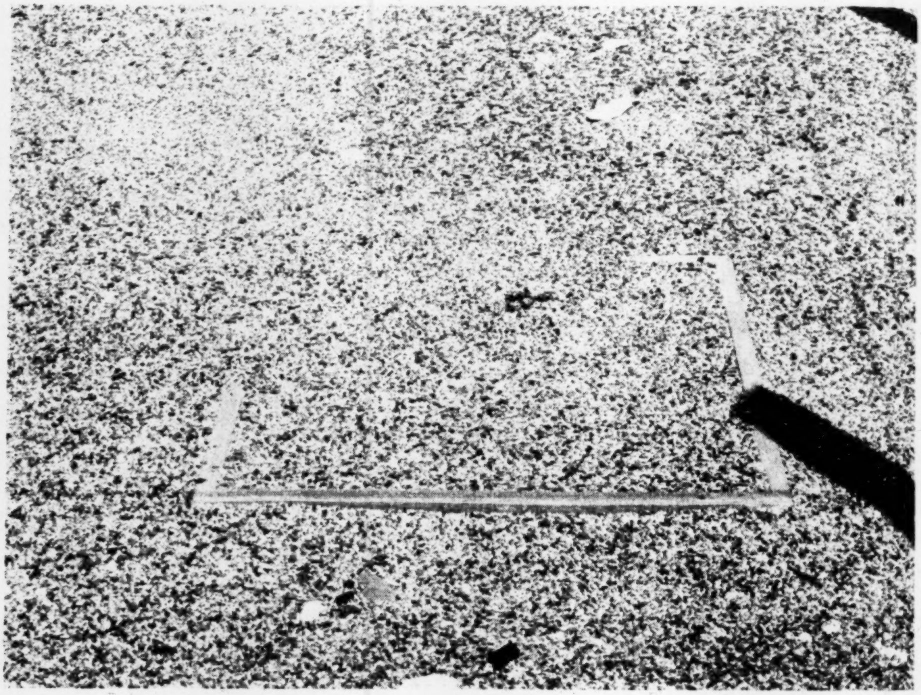
Large sand funnels or sand funnel-tubes are not feasible because of the large amounts of funnel sand required. The small sand funnel-tube gave excellent results in the graded Ottawa sand but rather poor results in the Ottawa 20-30 sand. Because some methods appear to be better in one type of sand than in another and because the number of tests in the graded Ottawa sand were more limited than the number in Ottawa 20-30 sand, it is felt that additional testing in the graded sand should be performed before more definite conclusions can be drawn. It is believed that whichever type of density-testing method may be employed, the equipment should first be calibrated in the laboratory for the type of sand to be tested in the field.

FIELD STUDIES

To establish field density controls, six boxes were installed on the beach at Point Mugu, Calif., in the latter part of October, 1952. The boxes of 1 × 1 ft inside dimensions were made of marine plywood with a perforated metal bottom to permit drainage. Cavities were excavated in the beach above high water and the boxes were installed with their tops flush with the adjacent surface of the beach. They were then allowed to fill with beach material by natural wind action. The boxes, spaced in two rows of three each, were 60 to 100 ft apart.

The original purpose of installing the field boxes was to determine whether the density of the material in the boxes would be the same as the density of the material adjacent to the boxes. A secondary but perhaps more important function of the boxes that developed was to provide direct field control of densities for certain test methods, namely, the plastic injection method and the small sand funnel-tube method. The boxes were not large enough to permit satisfactory testing inside of the boxes by the other methods.

Figure 12 illustrates a completely filled test box in the field just before it was tested. Plastic injection tests were performed inside some of the boxes, small sand funnel-tube tests were performed inside other boxes and all test methods were used in the area immediately surrounding the boxes.



Official Photograph U. S. Navy

FIG. 12.—Field Test Box Filled by Wind Action and Ready for Testing.

Of special interest were depth *versus* density tests made with the small sand-funnel tubes inside the test boxes. Four tests were made on each 2-in. increment of depth. The numerical average of the 24 tests inside the box at each location was very close to the numerical average of 24 similar tests made adjacent to the boxes, thus indicating that the density of the material in the box was a good measure of the density of the material surrounding the box. For the three locations, the data are tabulated as follows:

Location	Average Density from 24 Tests, g per cu cm		Actual Density in Box, g per cu cm	Average Water Content, per cent	
	Inside Box	Adjacent to Box		Inside Box	Adjacent to Box
1	1.700	1.668	1.621	3.81	0.77
2	1.740	1.737	1.662	2.64	1.08
3	1.764	1.753	1.648	2.94	1.36

If the data are plotted as depth *versus* density, there appears to be a decreasing density with depth to a depth of about 6 to 8 in., then an increasing density. In each case, inside the box the water content increased from nearly zero at the surface to a maximum of nearly 8 per cent for two of the boxes and to a maximum of about 14 per cent for the third box. Adjacent to the boxes the water content increased from nearly zero at the surface to a maximum of about 2 per cent for all three locations. If the data measured inside of the box are plotted as per cent error *versus* water content, there appears to be a decreasing per cent error with an increasing water content. This indicates that with the small sand funnel-tube measured densities of sands with higher water contents are less than measured densities of sands with lower water contents, at least within limits. But the data are probably insufficient to be conclusive and additional research is needed.

If the four surface tests for each of the three boxes above-mentioned are averaged and the per cent deviation of these values from actual box densities are plotted as ordinates *versus* the actual box densities as abscissas, there is an algebraically increasing error as the control density increases. This is just the opposite trend observed in the laboratory; however, the data are rather limited and therefore inconclusive. Additional field research of this type is needed.

CONCLUSIONS

The factor of prime importance divulged by the field density measurements is that all methods apparently have their own adjustment equation for each different type of sand. When the measured densities were adjusted by the density equations for the graded Ottawa sand and the Ottawa 20-30 sand, no reasonably close density was found common to the various methods for Point Mugu Beach sand. Apparently therefore all density-testing methods involving shearing action must be calibrated under controlled conditions in order to determine the proper equation to use to adjust field measured values more closely toward true values.

INVESTIGATION OF THE EFFECT OF TRANSIENT LOADING ON THE STRENGTH AND DEFORMATION CHARACTERISTICS OF SATURATED SANDS*

By H. B. Seed[1] and R. Lundgren[2]

A knowledge of the stress-deformation and strength characteristics of soils at very rapid rates of loading is required to determine the stability of earth structures when subjected to transient loads imposed by explosions, earthquakes, or traffic. Previous investigations (**1**)[3] have shown that under transient loading conditions saturated clay may exhibit a strength as much as 100 per cent greater than its strength under normal rates of load application, and a limited number of tests have indicated a similar increase in strength of dry sand of about 15 per cent. Problems encountered in recent years involving the stability of earth fill dams during earthquakes and the stability of saturated subgrades under traffic loading have indicated the need for an extension of these earlier investigations to include a study of the effects of transient loading on the strength of saturated granular materials.

The effects of rapid deformation on the strength of saturated cohesionless soils have been known qualitatively for many years (**2**). Deformation of a dense sand causes an increase in volume, termed dilatancy, and deformation of a loose sand causes a decrease in volume. Thus if a loose saturated sand is rapidly deformed, the grains tend to move into a more compact condition, and for this to occur, water must flow from the voids. If there is no time for drainage to occur, any load on the soil must be carried instantaneously by the pore water; hence, the pressure between the grains is considerably reduced, with a corresponding reduction in the shear strength of the soil. If the strength is reduced to zero, the sand is said to liquefy.

On the other hand, when a dense saturated sand is deformed, the void ratio is increased, and if there is no time for seepage into the sand, the water can no longer fill the voids. As a result the pore water is put in tension (sometimes called a negative pore-water pressure), thereby increasing the pressure between grains and causing a temporary increase in strength.

The void ratio at which a sand may be deformed without any change in volume occurring is called the critical void ratio. If there is no tendency for volume change, there is no tendency for water to enter or leave the sand; thus the strength should be the same whether drainage can occur or not. It should be possible, therefore, to determine the critical void ratio of a sand by determining the void ratio at which a saturated specimen has the same strength in both drained and undrained compression tests.

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13–18, 1954.

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[3] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 1306.

It follows from this brief discussion that the effect of transient loading on the strength of a saturated sand depends on the rate of deformation, the void ratio of the sand, and the rate at which drainage can occur. The purpose of the investigation described in this paper was to check the validity of these concepts, to determine the extent to which the strength of a saturated sand under transient loading may be increased by dilatancy effects, and to investigate any other effects of transient loading on the strength of saturated sands.

The investigation was conducted by performing triaxial compression tests, of the drained and undrained types, on specimens of fine and coarse sand at different void ratios and at different rates of loading. Since the effects of transient loading were to be determined by comparison of the strengths of specimens under identical conditions except for rate of loading and rate of drainage, all tests were performed using a lateral pressure of 2 kg per sq cm.

Experimental work by L. D. Leet (3) on the soil loading that would result from the explosion of 1000 lb of TNT indicates that in no case is the time required to reach maximum pressure less than 0.01 sec, and at a distance of 63 ft from the explosion, it was 0.025 sec. Furthermore, elastic waves caused by explosion of an atomic bomb had a period of 1 sec for the largest displacement, corresponding to a time of loading (time to reach maximum load) of 0.25 sec. A truck, moving at the rate of 60 mph, corresponds to a time of loading of the order of 0.01 sec at the point of contact, but the time of loading would be greater than this at points below the surface. On the basis of these data it was decided to investigate the effect of time of loading between the range of 0.02 sec and about 10 min. It was felt that this range includes all anticipated rates of loading due to earthquakes, wheel loads, and explosions, except those very close to a large explosion. Thus tests were made using three rates of loading:

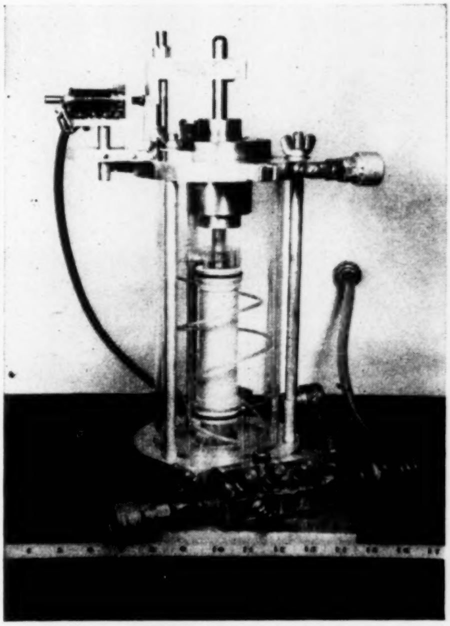


FIG. 1.—Triaxial Compression Cell.

1. *Static tests*—performed using a constant rate of load application so chosen that the time to reach maximum load is between 10 and 15 min. This type of loading is termed a "normal" rate of loading.

2. *Slow transient tests*—performed using a constant rate of deformation of 6 in. per min; for the tests in this investigation, this corresponds to a time of loading of about 4 sec.

3. *Rapid transient tests*—performed using a constant rate of deformation of

about 40 in. per sec; for the tests in this investigation, this corresponds to a time of loading of about 0.02 sec.

APPARATUS AND INSTRUMENTATION

Triaxial Compression Cell:

The triaxial compression cell used for the tests is shown in Fig. 1. Tests were performed on specimens 1.4 in. in diameter and approximately 4 in. high. The specimens were surrounded by a thin rubber membrane, which was securely bound to the cap and base; drainage lines from porous bronze plates in the cap and base to the lucite valve block enabled water to enter or leave the specimen. The specimen was immersed in water in the 4-in. diameter lucite cylinder, and an air pressure of 2 kg per sq cm was applied to the water. Axial load was applied to the specimen through a piston in the top of the cell. This $\frac{1}{2}$-in. diameter piston was guided by two precision-grade Thompson Ball Bushings, and piston friction was reduced to a minimum by using a loose fitting 0-ring as a seal. With this arrangement, friction was so low that the piston would move downwards under its own weight. There was a slight leakage of air around the seal, but the pressure was maintained constant by means of a pressure regulator.

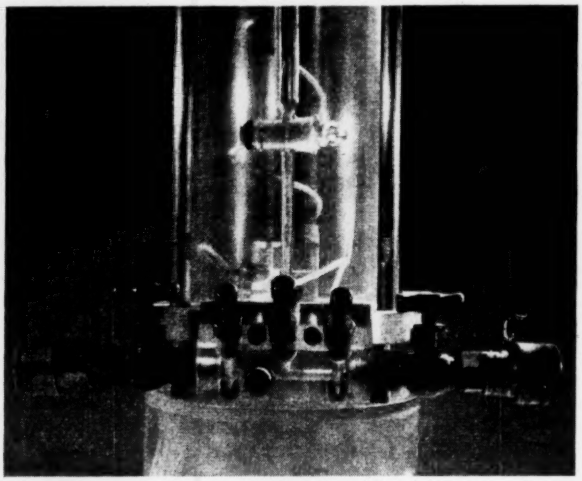


FIG. 2.—Lucite Valve Block.

A lucite valve block, Fig. 2, mounted on the front of the cell and connected to the cap and base of the specimen with $\frac{1}{8}$-in. diameter saran tubing made it possible to saturate the specimen after it was formed and also to allow the specimen to drain into a buret when desired. Drainage of water into or out of the buret during a static test was used to measure the change in volume of the specimen.

The specimen was saturated by subjecting the entire drainage system to a vacuum for about 15 min and then allowing deaired distilled water to enter the system through the valve block, pass upwards through the specimen, and then flow back to the valve block, with the vacuum maintained throughout.

A special cell, which had provisions for very rapid drainage, was used for the slow and rapid transient drained tests. This cell had a lucite base with a number of $\frac{1}{8}$-in. diameter holes drilled through it to connect a very porous bronze seat for

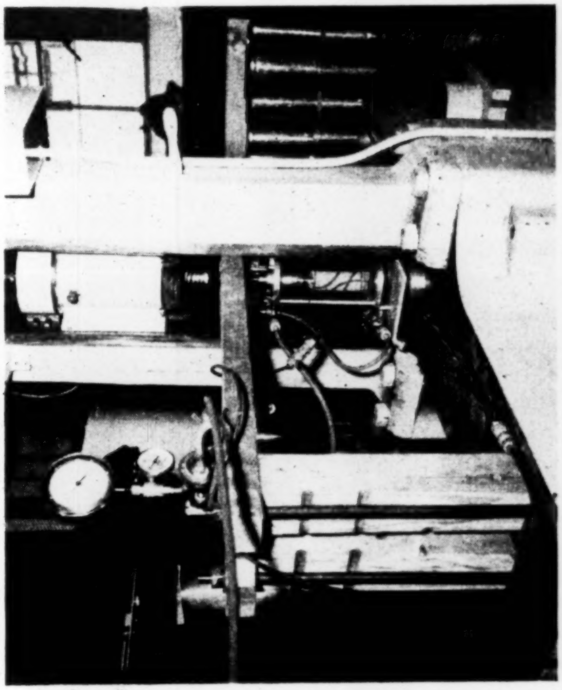


FIG. 4.—Rapid Transient Test.

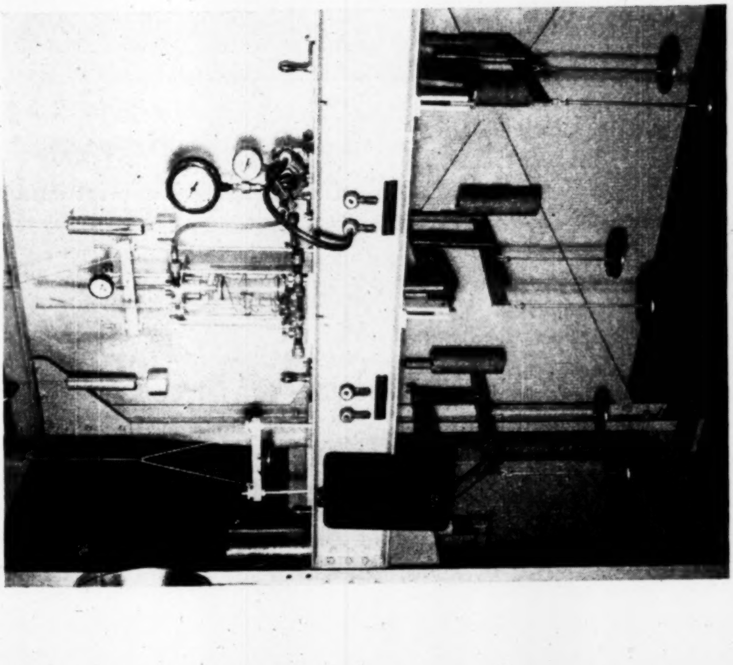


FIG. 3.—Static Test.

the specimen to a small reservoir at the base. The reservoir was connected by a $\frac{1}{2}$-in. diameter standard pipe and valve to a $\frac{1}{2}$-in. diameter standpipe. The permeability of this system was much greater than that of either of the sands used in the tests.

Loading Equipment:

For the static tests, the load was applied to the piston of the triaxial cell through a loading yoke connected to a lever system having a mechanical advantage of ten. A photograph of the loading system is shown in Fig. 3. The system is counterbalanced so that only the load applied to the hanger is transmitted to the specimen.

For the slow transient tests, the loading apparatus consisted of a standard 60,000-lb capacity Southwark-Tate-Emery testing machine having a platform with a rate of travel that could be varied from 0 to 6 in. per min.

A Hatt-Turner impact testing machine, Fig. 4, was used to apply loads in the rapid transient tests. This impact machine consists of a 50-lb weight which is allowed to fall in guides from any desired height onto the test specimen. For the tests in this investigation the weight was allowed to fall through a height of 4 in. before striking a spring on top of the loading piston. The weight then traveled 1 in. before its movement was arrested by wooden stops. At the time the weight struck the spring and piston, it was traveling at a rate of about 120 in. per sec. The change in velocity of the weight after striking the loading piston was negligible, and test data indicates that this impact test produced a very nearly constant rate of deformation of the specimen.

Load Gages for Transient Tests:

For measuring the load on the specimen in the transient tests, two load gages were used, one mounted on the piston of the triaxial cell and one placed below the triaxial cell, as shown in Fig. 4. The hollow tube pilon type of dynamometer was found suitable for this purpose.

For measuring load at the upper end of the specimen, a piece of $1\frac{1}{4}$-in. diameeter thin-wall 24S-T aluminum tubing was machined to the desired size and shape. Eight 120-ohm SR-4 strain gages, four vertical and four horizontal, were glued onto this piece of tubing. All opposing gages, vertical to vertical and horizontal to horizontal, were wired in series to form four pairs; then each one of these pairs was used as a leg to form a bridge. The gages were protected by black plastic tape wrapping. This pilon type dynamometer, designed to carry a maximum load of 750 lb, was accurate to the nearest 5 lb and had a natural frequency of vibration somewhere in the order of 10,000 cps.

For measuring load at the bottom end of the specimen, sixteen gages were glued on a machined piece of $4\frac{1}{2}$-in. diameter thin-wall 24S-T aluminum tubing. The wiring for this pilon was the same as for the top pilon except that four gages 90 deg apart were wired in series, instead of only two opposing gages being wired in series.

The change in resistance of the strain gages as load was applied during a test was amplified and measured by a Hathaway Oscillograph. The calibration of resistance change with load for each dynamometer was established following each test.

Deformation Gage for Transient Tests:

The deformation of the specimen in the transient tests was measured by an inductance type of deflection gage. This type of gage offers no vibration problems, has no measurable time-lag between the actual deformation of the specimen and the recorded deformation even at high velocities, and is accurate to the nearest 0.02 in. over a 1-in. range.

A photograph of the gage is shown in Fig. 5. Two coils were wound on hollow lucite spools. One coil was a dummy and contained an adjustable iron core for the purpose of balancing the bridge circuit, though the core was stationary during a test. The other coil contained an iron core that was forced into or out of the center of the coil by a mechanical arrangement attached to the piston of the triaxial cell. This mechanical arrangement reduced the movement of the core so that a 1-in. deflection of the specimen would move the core only 0.1 in., thus keeping the output of the coil in a linear range and also reducing inertia effects in the deflection gage by reducing the velocity of mechanically moving parts. The movement of this iron core caused a change in impedance of the coil, and this change in impedance was amplified and measured on the Hathaway Oscillograph. The calibration of impedance change with deflection was established following each test.

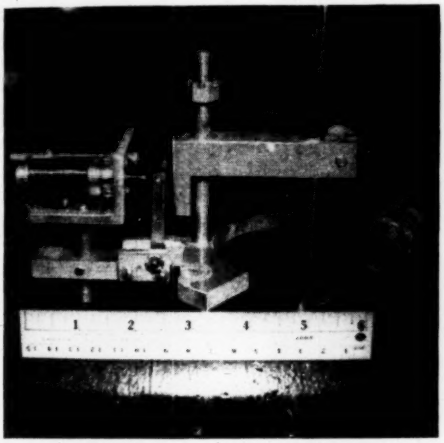


FIG. 5.—Deformation Gage.

Amplification of Electrical Signal:

A Hathaway Modulated Carrier Amplifier, Model MRC 15c, was used to balance the Wheatstone bridge circuits of the load and deformation gages and also to amplify any changes in balance caused by deformation of these gages. An alternating 3500 cps carrier current is demodulated after the last stage of the amplifier, leaving a direct-current output that is proportional to the deformation of the gages.

Recording Oscillograph:

A Hathaway Oscillograph, Model S8-C, equipped with OA-2 galvanometers having a natural frequency of 3500 cps, was used to record the electrical signals on a moving strip of light-sensitized paper. The rate of movement of the sensitized paper was 1 in. per sec for the slow transient tests, and 40 in. per sec for the rapid transient tests. Timing lines were recorded on the paper at 0.01-sec intervals.

RESULTS OF TESTS ON FINE SAND

The sand used in these tests was a fine grained sand with fairly smooth subrounded particles, from the Sacramento River, Calif. The sand had previously been washed for use in concrete and was therefore quite clean. Only the portion passing the No. 100 sieve was used in the investigations. The grain size distribution curve of the sand used is shown in Fig. 6.

Static Tests:

Typical stress-strain curves for static drained and static undrained tests on specimens of loose and dense fine sand are shown in Fig. 7. The change in cross-sectional area due to bulging of the specimen during loading was taken into account in the computation of the applied stress; the maximum deviator stress—that is, the maximum difference between

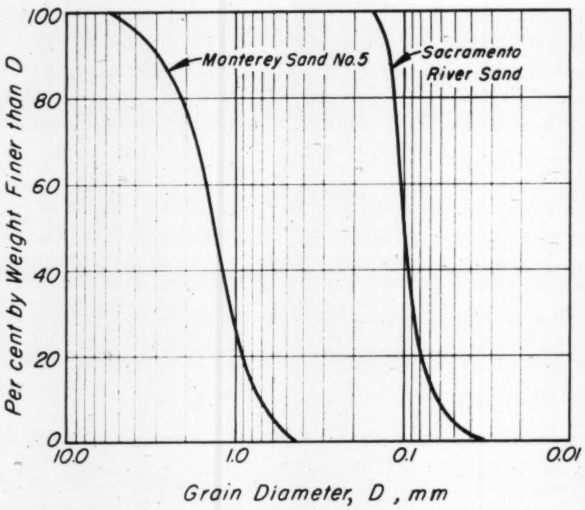


FIG. 6.—Grain Size Characteristics of Sands Used in Tests.

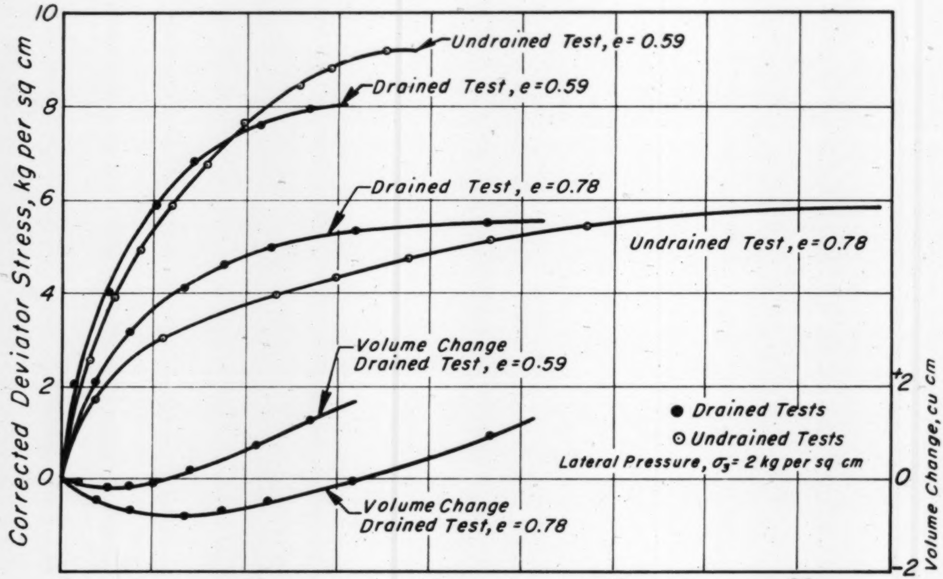


FIG. 7.—Stress and Volume Change *versus* Strain for Drained and Undrained **Static Tests** (Sacramento River Sand).

major and minor principal stresses obtained during a test—was considered to be the compressive strength of the sample.

The volume changes occurring during deformation of the specimens of loose and dense fine sand in the static drained tests are also plotted in Fig. 7. Both loose and dense specimens first decrease and then increase in volume as deformation increases.

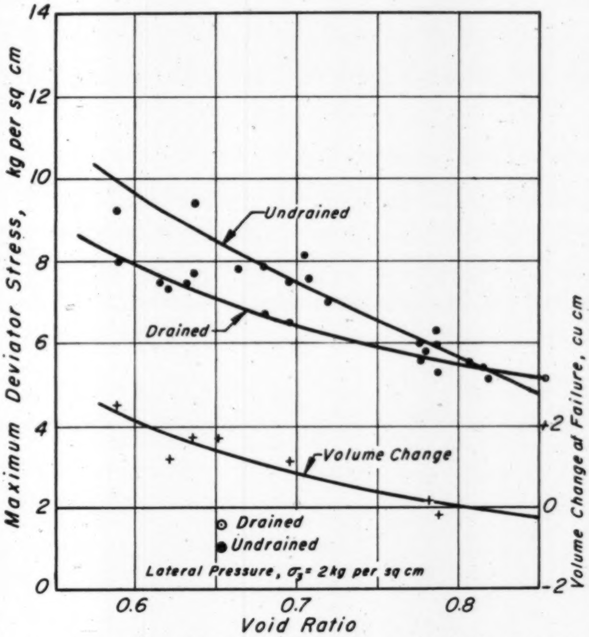
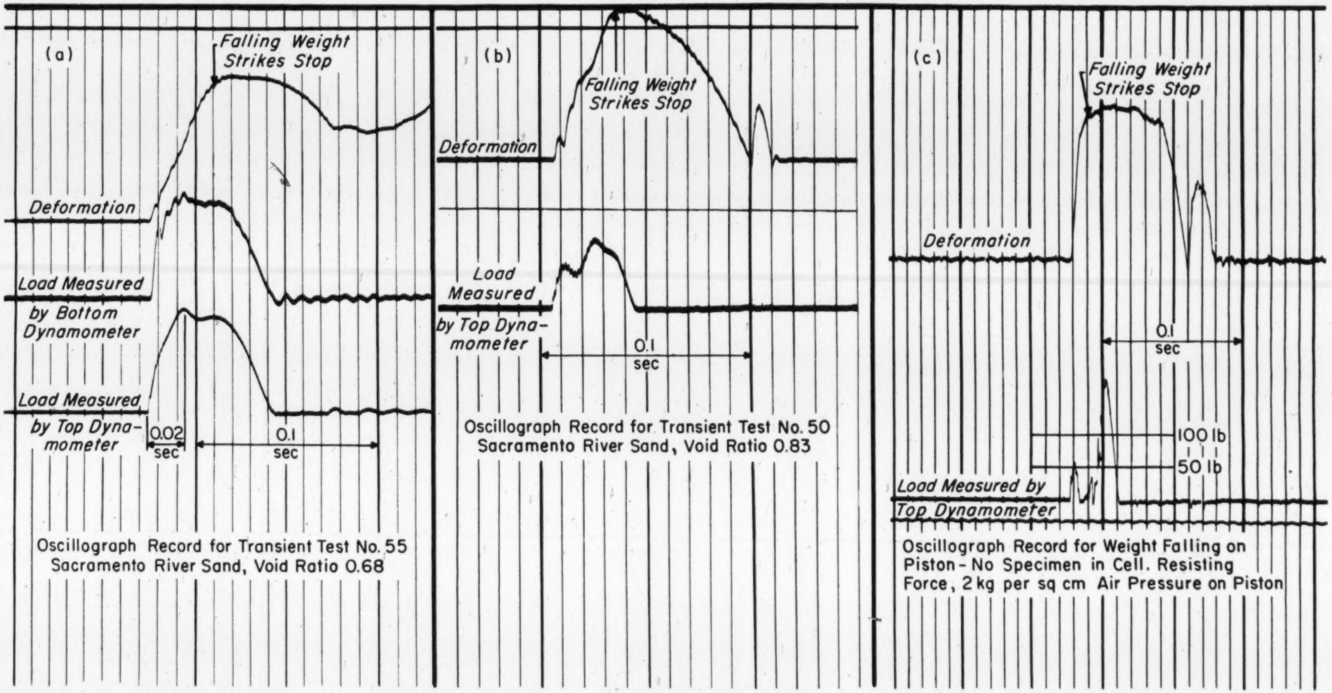


FIG. 8.—Compressive Strength and Volume Change *versus* Void Ratio for Static Tests (Sacramento River Sand).

The values of maximum deviator stress occurring in a number of drained and undrained tests on specimens of fine sand at various initial void ratios are plotted in Fig. 8. The changes in volume of the specimens at failure in the drained tests are also shown. It will be seen that for dense specimens at the same void ratio the strength in an undrained test is about 20 per cent greater than the strength in a drained test. This increase in strength in undrained tests must be attributed to the negative pore-water pressures that develop due to dilatancy effects during deformation of a dense sand when no drainage can occur. A strength increase due to dilatancy of 20 per cent would be equivalent to a negative pore-water pressure of 20 per cent of the applied lateral pressure. Since the lateral pressure used was 2 kg per sq cm, the equivalent negative pore-water pressure would be 0.4 kg per sq cm.

As the initial void ratio of the test specimen increases, the difference between the strength in drained and undrained tests decreases. For an initial void ratio of about 0.81, the same strength is developed whether the specimen is tested in a drained or undrained condition; this void ratio should therefore correspond closely to the critical void ratio. From the volume change-at-failure



Oscillograph Record for Transient Test No. 55
Sacramento River Sand, Void Ratio 0.68

Oscillograph Record for Transient Test No. 50
Sacramento River Sand, Void Ratio 0.83

Oscillograph Record for Weight Falling on Piston - No Specimen in Cell. Resisting Force, 2 kg per sq cm Air Pressure on Piston

FIG. 9.—Oscillograph Records.

data in Fig. 8, the critical void ratio (that is, the initial void ratio at which there is no change in volume at failure) of the fine sand under a lateral pressure of 2 kg per sq cm is seen to be about 0.8. This is in good agreement with the value of 0.81 determined by the initial void ratio for which the strengths in drained and undrained tests are the same.

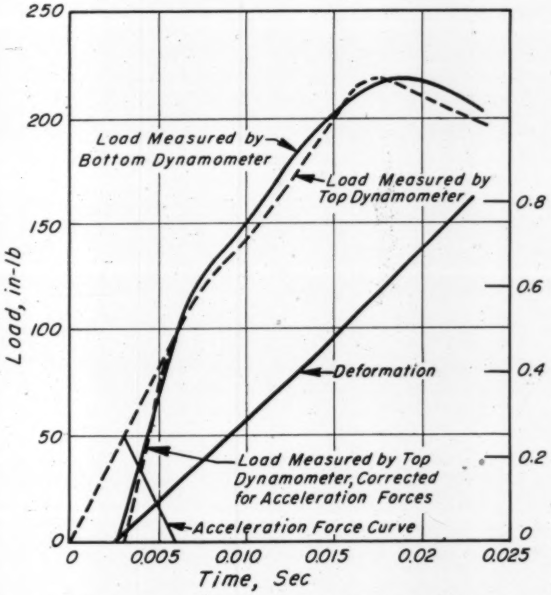


FIG. 10.—Load and Deformation *versus* Time, Undrained Test No. 55, Void Ratio 0.68 (Sacramento River Sand).

Rapid Transient Tests:

Load and deflection relationships occurring during rapid transient tests were recorded on oscillograms which were then used to plot load and deflection *versus* time curves. Typical oscillograms are shown in Fig. 9. The increases in load and deflection with time in test No. 55, as determined from the oscillogram in Fig. 9(*a*), are shown in Fig. 10.

It may be seen that on the oscillograms in Figs. 9(*a*) and (*b*) the upper dynamometer starts to record before either the bottom dynamometer or the strain gage. This premature indication of load was believed to be caused by the force required to accelerate the piston and other moving parts of the test equipment from the stationary position to the final rate of deformation. To investigate the magnitude and rate of development of these acceleration forces, tests were performed with the equipment assembled exactly as for transient tests except that no specimen was inserted below the piston. The only resistance to movement of the piston was the 2 kg per sq cm air pressure in the cell. An oscillogram obtained in such a test is shown in Fig. 9(*c*). It will be seen that a load of about 50 lb was recorded by the dynamometer when the deflection was extremely small. Shortly thereafter the deformation velocity became constant and the acceleration force decreased to zero. The acceleration force of 50 lb was built up in about 0.003 sec and then dropped off to zero in about the same amount of time. In reducing the test results, the acceleration force-time curve was deducted from the load-time curve recorded by the top dynamometer, as shown in Fig. 10, to obtain the true load-time curve for the sample. It may be seen that the corrected load-time curve obtained in this way agrees very closely with the load-time curve recorded by the bottom dynamometer, which was not affected by acceleration forces.

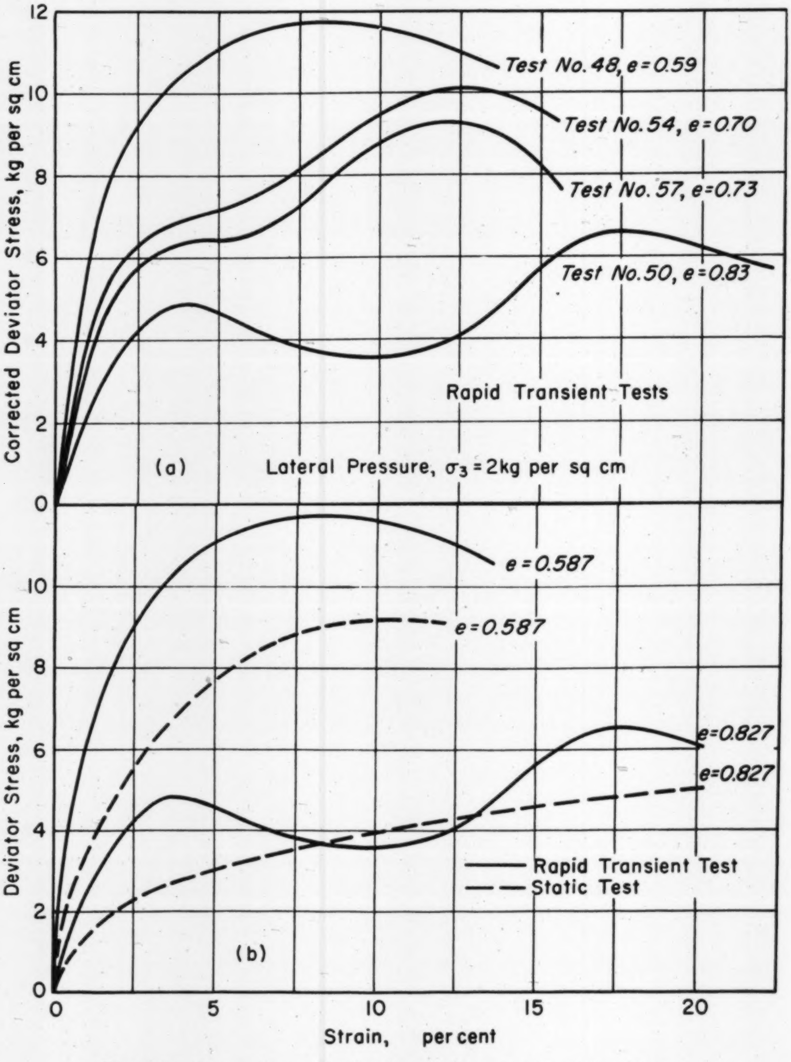


FIG. 11.—Stress *versus* Strain Curves (Sacramento River Sand).
(*a*) Rapid transient tests.
(*b*) Rapid transient and static tests.

In making the correction for accelera-

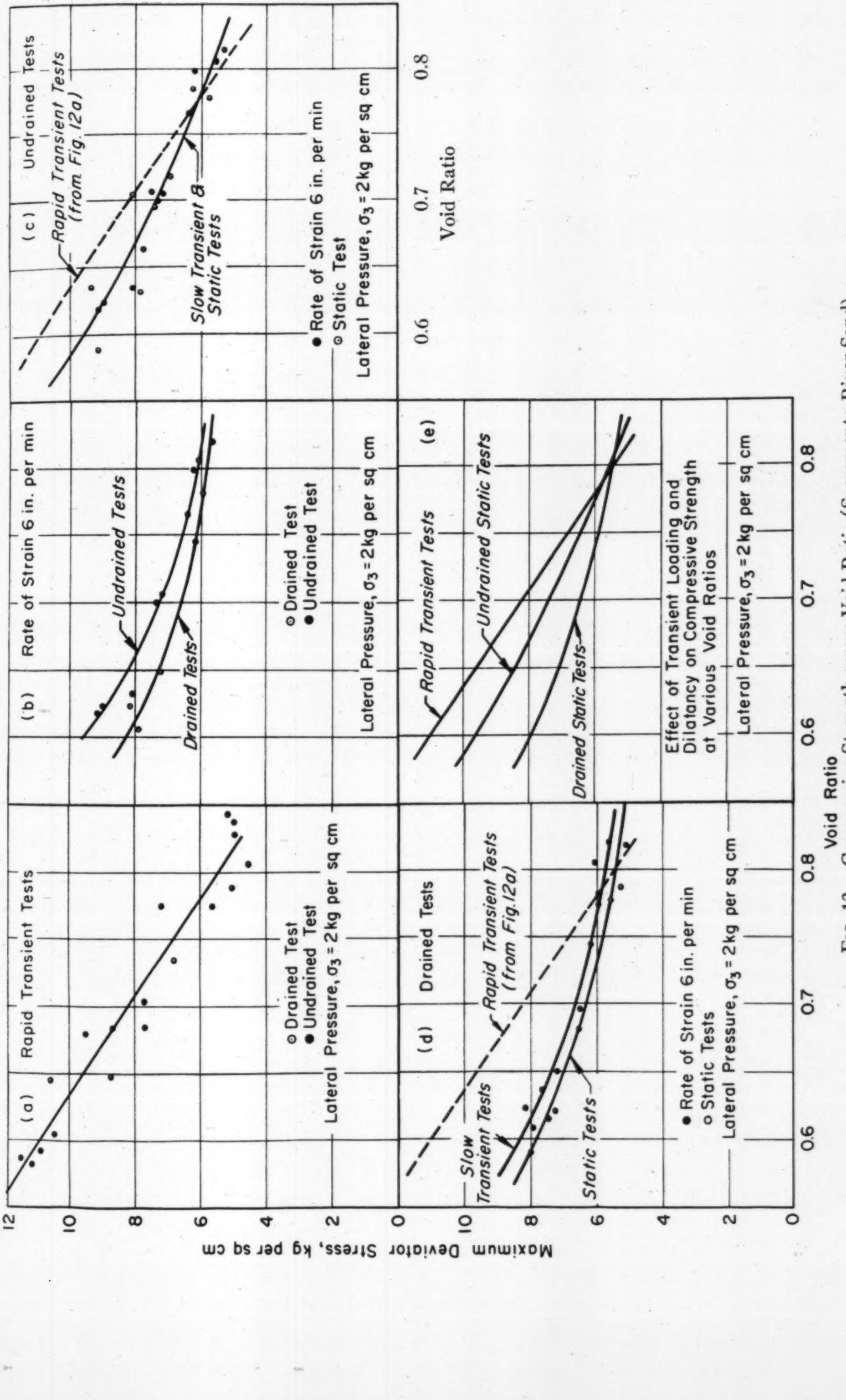


FIG. 12.—Compressive Strength *versus* Void Ratio (Sacramento River Sand).

tion forces described above, it was assumed that the acceleration forces developed with a specimen in the triaxial cell would be the same as those developed with no specimen in the cell. That this assumption is justified is shown by the good agreement obtained between the load-time curves measured by the bottom dynamometer and the corrected load-time curves for the upper dynamometer (Fig. 10).

It will be seen in Fig. 9(*c*) that the acceleration force decreases to zero in about 0.006 sec. In the tests, maximum load was reached in a period of time varying from 0.017 to 0.020 sec after the upper dynamometer started to record. Thus, although acceleration forces may affect the initial part of the stress-strain curves, they will not affect recorded values of the load required to cause failure. From the load and deflection *versus* time curves, shown in Fig. 10, the stress *versus* strain relationships in the transient tests were determined.

Typical stress-strain curves obtained in tests on specimens of fine sand at void ratios ranging from loose to dense are shown in Fig. 11(*a*). The values of maximum deviator stress obtained in fast transient drained and undrained tests on specimens of fine sand at various void ratios are plotted in Fig. 12(*a*). It will be seen that the strengths obtained in the drained tests are essentially the same as those obtained in the undrained tests. This would seem to indicate that, although provisions are made for drainage to take place, in a drained test the rate of loading is so fast that there is no time for drainage to occur. Thus, in effect, a fast transient test with the drainage lines open is actually a fast transient undrained test.

Slow Transient Tests:

Stress-strain relationships for slow transient drained and undrained tests were obtained by means of oscillograms in the same manner as for rapid transient tests. The maximum deviator stresses in drained and undrained tests for various void ratios are plotted in Fig. 12(*b*). It will be seen that the strength of a specimen in an undrained test is somewhat greater than that of a specimen of equal void ratio in a drained test. However, the difference in drained and undrained strengths is not so great as was the case for static tests.

EFFECT OF RATE OF LOADING ON COMPRESSIVE STRENGTH

Since all rapid transient tests are undrained, the effect of rate of loading (as distinct from dilatancy effects) in these tests can be determined only by comparison of the results with the strength of samples in other undrained tests conducted at various rates of loading. In all undrained tests there will be a strength increase due to dilatancy, but this should be the same for all rates of loading. Thus any difference in the results may be attributed to the rate of loading.

The strengths of specimens at various void ratios in static, slow transient, and rapid transient undrained tests, are compared in Fig. 12(*c*). Within the limits of experimental error the strengths in static and slow transient tests are the same for specimens of equal void ratios. However, the strengths of dense specimens in rapid transient tests are about 15 to 20 per cent greater than the strengths of similar specimens in static or slow transient tests. This strength increase of 15 to 20 per cent in transient tests agrees well with the increase of 10 to 15 per cent reported by Casagrande and Shannon (1) for tests on dry sand.

As the void ratio increases, the effect of rate of loading decreases, and at an initial void ratio of about 0.78, rate of loading has no appreciable effect. At void ratios above this, the strength in rapid transient tests is lower than in static tests. The cause of this lower strength is discussed under the section on Liquefaction.

EFFECTS OF DILATANCY AND RATE OF LOADING ON COMPRESSIVE STRENGTH

A comparison of the strengths in rapid transient drained tests with those obtained in static and slow transient drained tests is shown in Fig. 12(*d*). It will be seen that the strengths in slow transient tests are somewhat greater than those of similar specimens in static tests. Since, as shown above, the rate of loading does not appear to affect the strength in slow transient tests, this difference must be attributed to different degrees of drainage. It would appear, therefore, that complete drainage does not have time to occur even in a slow transient test, and the resulting negative pore-water pressure causes the strength to be greater than that of a completely drained specimen.

The strengths of dense specimens in fast transient drained tests are considerably greater than the strengths in static drained tests (Fig. 12(*d*)). From the above discussion it will be seen that this strength increase in rapid transient tests is due to two causes: (1) the development of negative pore-water pressures due to dilatancy effects and to the fact that drainage does not occur, so that the test is really an undrained test, and (2) the strength increase due to the high rate of loading. A combination of these two effects causes the strength of a dense specimen in a rapid transient test to be about 40 per cent greater than that of a similar specimen in a static drained test. However, the magnitude of this strength increase decreases with increasing void ratio, and it should be remembered that the strength increase of 40 per cent for dense specimens is true only for the test conditions used in this investigation—that is, for a lateral confining pressure of 2 kg per sq cm.

The separate effects of dilatancy combined with lack of drainage and of rate of loading on the strength of a saturated sand under transient loading conditions are shown in Fig. 12(*e*). The effect of dilatancy and lack of drainage is determined by comparison of the strengths of specimens in static drained and static undrained tests, and the effect of rate of loading is determined by comparison of the strengths in static undrained and rapid transient tests. Since static drained tests give results similar to those obtained in tests on dry sand, it may be concluded that the rapid transient strength of a dense saturated sample in this investigation is about 40 per cent greater than the strength of a dry specimen at the same void ratio in a static test; of this increase in strength, about 20 per cent is due to the high rate of loading, and the remainder is due to the development of a negative pore-water pressure of about 0.4 kg per sq cm.

These results enable an estimate to be made of the strength increase, over that obtained in static tests on dry specimens, in rapid transient tests conducted with different lateral pressures. For example, if a rapid transient test on a dense specimen were conducted using a lateral pressure of 1 kg per sq cm, then assuming that dilatancy effects would again cause a negative pore-water pressure of 0.4 kg per sq cm, the strength increase due to this cause would be about 40 per cent. The strength increase due to the high rate of loading would be about 20 per cent. Hence the strength of a dense saturated specimen in a rapid transient test would be about 60 per cent greater than that of a dry specimen at the same void ratio in a static test.

Liquefaction

It is known that rapid deformation or vibration of a loose saturated sand will cause liquefaction of the sand and a complete loss of shear strength for a short interval of time. This phenomenon is attributed to the increase in pore-water pressure as the water moves out of the voids. If the deformation is sufficiently slow that the water can drain without developing a high pore-water pressure, then there is no loss of strength. However, if the rate of deformation exceeds the rate of drainage, pore-water pressures will develop and a loss of strength will result.

In spite of the established fact that liquefaction of a loose saturated sand can occur, the difficulty of obtaining liquefaction in laboratory compression tests on loose saturated sands has been recognized for some time. Even in an undrained type of test, where presumably no drainage can occur, under normal rates of loading there is usually no indication of any loss of shear strength during the test. This is probably due partly to the difficulty of preparing a specimen of sand for laboratory tests at a void ratio appreciably greater than the critical void ratio, with the result that the decrease in void ratio during deformation is quite small, and partly to the difficulty of preventing drainage even in an undrained type of test. Without elaborate precautions it is practically impossible to remove all the air from a sample and from the drainage system by means of which the sample is saturated; in addition, the drainage system may expand somewhat if the pore-water pressure is increased, thus causing a relief of pressure. If the water can compress air or expand the system sufficiently instead of developing pore-water pressures, then liquefaction will not occur.

The results obtained in rapid transient tests on loose saturated specimens of fine sand show that the resistance of the specimen first increases as it is deformed but then decreases appreciably with further increase in deformation; subsequent deformations then cause another increase in resistance. This may be seen from the load - time curve in the oscillogram in Fig. 9(*b*) and from the stress *versus* strain relationship determined from this oscillogram in Fig. 11(*b*). Also shown in Fig. 11(*b*) is a stress *versus* strain curve for a static undrained test on a specimen of equal void ratio. It will be seen that the specimen under transient loading has the higher resistance for small strains but a lower resistance for large strains. Up to a strain of about 3.5 per cent, the specimen in the transient test shows a progressively increasing resistance to deformation, but with further increase in strain, resistance decreases. It is believed that this loss of strength when the strain exceeds about 3.5 per cent is due to partial liquefaction of the sand. It appears, therefore, that in rapid transient tests on fine sand the rate of loading is so fast that, when a pore-water pressure develops, considerable deformation occurs before the pressure is completely relieved by drainage or by the increase in volume that occurs even in loose sand at high strains (see Fig. 7). It is interesting to note that a deformation of about 3.5 per cent occurs before there is any loss of strength. For purposes of comparison, the stress *versus* strain curves obtained in rapid transient and static undrained tests on dense specimens of sand at equal void ratios are also shown in Fig. 11(*b*). The fact that there is some evidence of liquefaction in rapid transient tests at void ratios which show no evidence of liquefaction in static tests would seem to indicate that the critical void ratio determined by static tests may be somewhat higher than that at which liquefaction will occur.

The rapid transient tests demonstrate

that it is possible to produce some degree of liquefaction in the laboratory. If greater care were taken to remove all the air from the voids, and the drainage system were less expansive, it would probably be possible to cause liquefaction of the fine sand at a still lower void ratio than is indicated by these tests. A carefully conducted rapid transient test might provide a reliable means of determining the critical void ratio at which a sand will become susceptible to liquefaction.

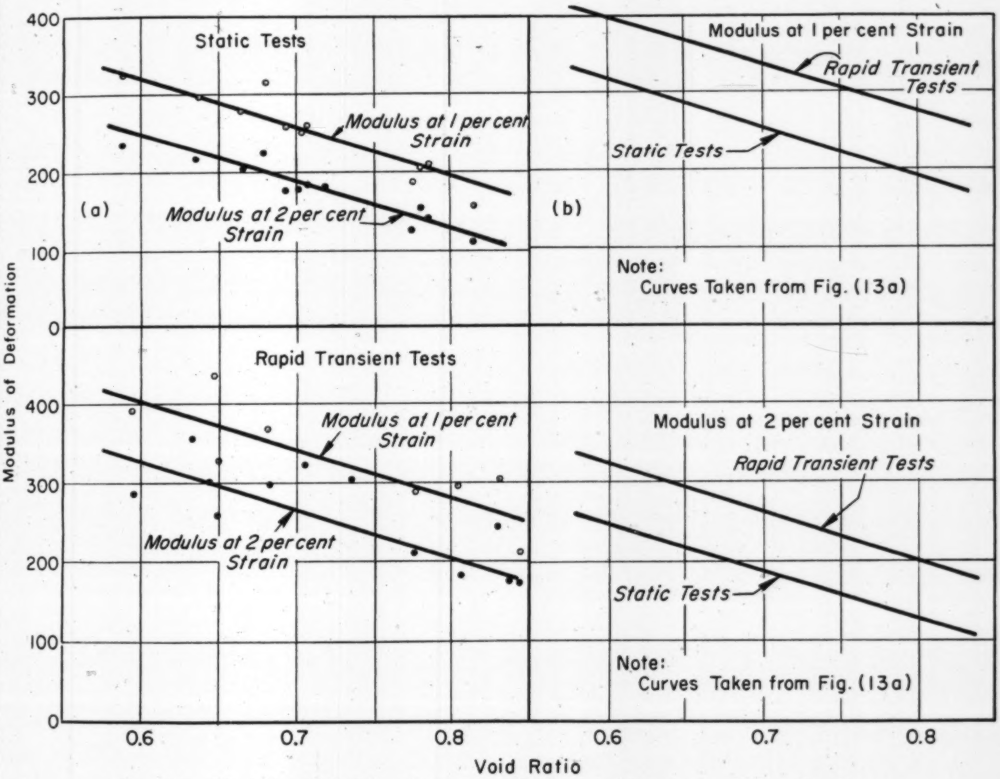


FIG. 13.—Modulus of Deformation *versus* Void Ratio (Sacramento River Sand).

MODULUS OF DEFORMATION

In computing the velocity of propagation of stress waves through soils and the effects of vibrations on structures embedded in soils, it is necessary to know the modulus of deformation of the soil. Modulus of deformation is defined as the ratio of stress to strain at a particular strain.

Moduli of deformation at 1 and 2 per cent strains determined by rapid transient and static undrained tests on the fine sand are shown in Fig. 13(*a*). The results show that the modulus of deformation at 1 per cent strain is approximately 30 per cent greater than the modulus at 2 per cent strain for both static and rapid transient tests.

The moduli of deformation at both 1 and 2 per cent strains determined by rapid transient and static undrained tests at various void ratios are compared

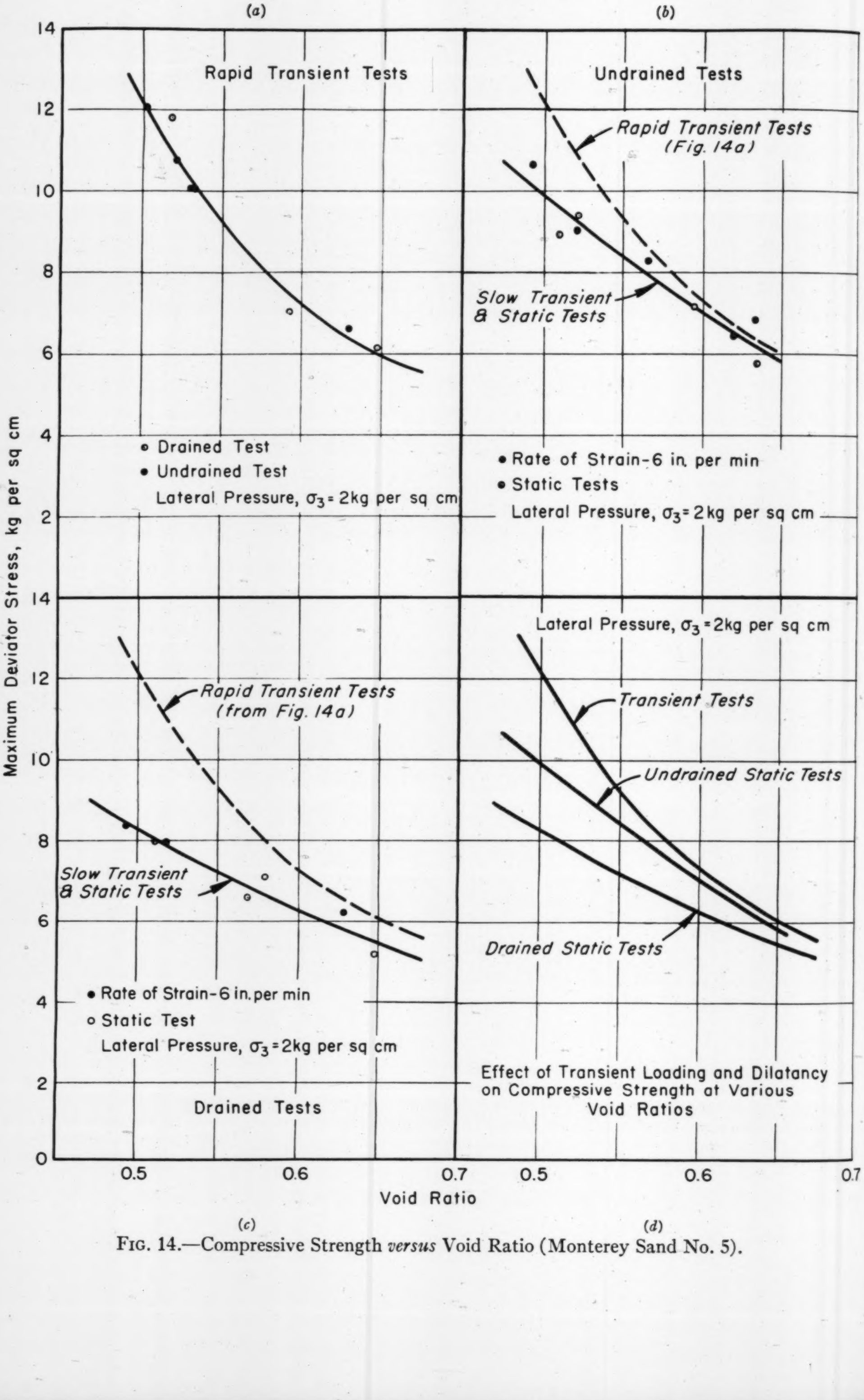


FIG. 14.—Compressive Strength *versus* Void Ratio (Monterey Sand No. 5).

in Fig. 13(*b*). In both cases, at any given void ratio, the modulus of deformation determined by a rapid transient test is about 30 per cent greater than the modulus determined by a static test.

RESULTS OF TESTS ON COARSE SAND

A series of tests similar to those described above was performed on a coarse uniform sand from Monterey, Calif. The Monterey No. 5 sand consists of subrounded particles passing the No. 4 sieve but retained on a No. 50 sieve. A grain size distribution curve is shown in Fig. 6.

The test results are summarized in Fig. 14. The strengths of saturated samples having various initial void ratios ranging from dense to loose in rapid transient drained and undrained tests are shown in Fig. 14(*a*). It will be seen that the strengths are for all practical purposes the same whether the test is of the drained or the undrained type. Thus it may be concluded that even for a coarse sand the rate of loading in a rapid transient test is so high that there is no time for drainage to occur and therefore all tests are actually undrained.

The results of static, slow transient, and rapid transient undrained tests are compared in Fig. 14(*b*). The strength values in static and slow transient tests on specimens of equal void ratios are for all practical purposes the same, and therefore it would appear that the rate of loading in these tests has no influence on the results. However, the strengths in rapid transient tests on dense specimens are about 15 to 20 per cent greater than the strengths obtained in slow transient or static tests. The effect of the high rate of loading in rapid transient tests is thus very similar to the effect observed in tests on fine sand.

The strengths of samples in drained tests using three different rates of loading are compared in Fig. 14(*c*). Here again the strength values in slow transient and static tests are the same; this was not the case in the tests on fine sand. Presumably for the coarse sand there is sufficient time, even in slow transient tests, for complete drainage to occur, due to the high permeability of the material. Thus negative pore-water pressures do not develop as in the case of fine sand. In rapid transient tests, however, no drainage occurs. Thus for dense specimens the results of these tests are considerably greater than for slow transient or static tests; the combined effects of dilatancy and rate of loading result in a strength increase of about 40 per cent.

The results of these tests are summarized in Fig. 14(*d*). A comparison of the strengths determined in static drained and static undrained tests again shows that for dense specimens the strength in an undrained test is about 20 per cent higher than in a drained test, corresponding to the development of a negative pore-water pressure of about 0.4 kg per sq cm. In addition, a fast transient rate of loading causes a further increase in strength of about 15 to 20 per cent.

There was no evidence of liquefaction in any of the tests conducted on loose samples of coarse sand.

CONCLUSIONS

The main conclusions resulting from the tests performed in this investigation may be summarized as follows:

1. The strength of a dense saturated sand under transient loading conditions is greater than for normal rates of loading due to (1) the effects of dilatancy combined with lack of drainage and (2) the effects of the rate of deformation.

2. In addition to any strength increase caused by dilatancy and lack of drainage, deformation of a dense sand at the rate of 40 in. per sec causes an increase in

strength of about 15 to 20 per cent over the strength for normal rates of loading; a rate of deformation of 6 in. per min has no measurable effect on the strength for normal rates of loading.

3. Laboratory tests on dense, saturated specimens of coarse and fine sand using a confining pressure of 2 kg per sq cm show that if no drainage can occur dilatancy effects will cause the strength to be greater than the strength in the fully drained condition; the amount of this increase is equivalent to that resulting from an increase of 0.4 kg per sq cm in the confining pressure.

4. The effects of rate of loading and dilatancy on the strength of a saturated sand decrease as the void ratio increases.

5. A specimen of loose saturated fine sand may show a lower strength in a laboratory compression test with a very high rate of loading than in an undrained test with a normal rate of loading.

6. For strains up to about 2 per cent, the modulus of deformation determined by a rapid transient test on a specimen of saturated fine sand is about 30 per cent greater than that determined by a static test on a similar specimen of equal void ratio.

REFERENCES

(1) A. Casagrande and W. L. Shannon, "Research on Stress-Deformation and Strength Characteristics of Soils and Soft Rocks under Transient Loading," *Soil Mechanics Series, No. 31*, Harvard University, June, 1948.

(2) A. Casagrande, "Characteristics of Cohesionless Soils Affecting the Stability of Slopes and Earth Fills," *Journal*, Boston Soc. Civil Engrs., January, 1936.

(3) L. D. Leet, "Earth Motion from the Atomic Bomb Test," *American Scientist*, Vol. 34, pp. 198–207 (1946).

EFFECT OF CRYSTALLINITY AND CRAZING, AGING, AND RESIDUAL STRESS ON CREEP OF MONOCHLOROTRIFLUOROETHYLENE, CANVAS LAMINATE, AND POLYVINYL CHLORIDE, RESPECTIVELY*

By William N. Findley[1]

Synopsis

Results of tension creep tests at 77 F and 50 per cent relative humidity are presented which show the effect of the following variables: (*a*) the degree of crystallization of monochlorotrifluoroethylene (Kel-F), (*b*) residual stresses remaining after fabrication of sheets of polyvinyl chloride (Geon 404), and (*c*) aging of grade-C canvas laminate at 77 F and 50 per cent relative humidity.

The monochlorotrifluoroethylene was tested in the amorphous, fully crystalline and intermediate (commercial) state. The effect of residual stresses was shown by tests of samples of polyvinyl chloride before and after an anneal at 275 F which resulted in shrinkage of the material. The canvas laminate was tested in creep before and after aging at constant temperature and humidity for about ten years.

The effect of different degrees of crystallinity, residual stress, and aging on creep of materials has not received wide attention. The only work on these topics for plastics which has been reported, as far as is known, is a study of the effect of aging on creep of cellulose acetate (**1**)[2] and a creep test method for determining the cracking sensitivity of polyethylene polymers (**2**).

Of course, most engineering materials are not available with a wide range in degree of crystallinity. Metals, for example, are largely crystalline and contain only minute but important regions of amorphous material at the grain boundaries. Changes in structure with time are found in other engineering materials besides plastics at certain temperatures, such as steels at high temperatures. Residual stresses may be found in many applications of many materials. Usually residual stresses are relatively low in magnitude at temperatures where creep becomes significant in many engineering materials, such as high-temperature steels.

The effect of residual stresses in plastics has often been observed. Means of reducing these stresses and the theory and measurement of residual stresses for

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[2] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 1312.

plastics have been considered by some investigators. Crazing of plastics has been the subject of several investigations. For linear polymers, crazing has been described as a mechanical separation of polymer chains or groups of chains under the action of tensile stress, and starting in a region where the polymer chains are oriented at right angles to the tensile stress. References to these topics are given in a feature article in *Applied Mechanics Reviews* (3).

Materials:

Monochlorotrifluoroethylene of grade 300 Kel-F was obtained in sheets of $\frac{1}{8}$-in. thickness from the M. W. Kellogg Co. This grade was unplasticized and represents the highest molecular weight in the form of molding powder. The high density molding powder had a compression ratio of 2 to 1. The sheets were compression molded under a pressure of 2500 to 3000 psi and at a temperature of 480 to 500 F. Immediately after pressing, a sheet was quenched in water to produce the amorphous sample. Another sample was cooled between platens which had cold water circulating through them to produce the material with intermediate crystallinity (commercial practice). The crystalline form was obtained after pressing by dropping the temperature quickly by means of steam to 450 F, then cooling to room temperature in the press. It required 6 to 8 hr to cool.

The grade-C canvas laminate employed in these tests was the same from

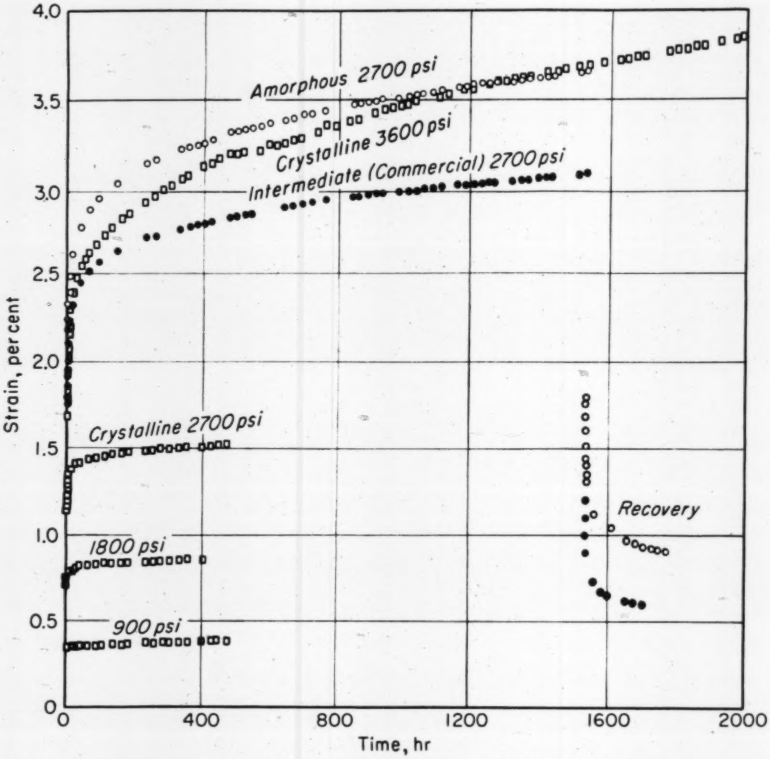

FIG. 1.—Creep Curves for Monochlorotrifluoroethylene at Different Stresses and Three Different Degrees of Crystallization—Temperature 77 F, Relative Humidity 50 per cent.

which test specimens were obtained for previous tests (4). A detailed description of the material is given in reference (4).

The polyvinyl chloride was obtained as a sheet of Geon 404 $\frac{9}{16}$ in. thick from the Nixon Nitration Works. The formulation was designated VX-108 Natural and contained no plasticizer, 3.3 per cent dibutal-tin diborate as a stabilizer, and 0.5 per cent stearic acid as a lubricant. The ingredients were mixed and blended at 280 F and calendered into sheets 0.02 in. thick on rolls having a temperature of 300 F. About 28 of these sheets were laminated together in a hydraulic press to form the final sheet and remove most of the residual strain resulting from the calendering. The sheets were subjected to a pressure of 280 psi at 315 F for about 30 min and then cooled rapidly in the press.

Specimens and Test Procedure:

The specimens and procedure employed for the creep tests were same as previously described (4) except that the specimens for creep tests of monochlorotrifluoroethylene and polyvinyl chloride had 4-in. gage length and the specimens of monochlorotrifluoroethylene were the thickness of the sheet instead of $\frac{5}{32}$ in. thick.

Results and Interpretation:

Figure 1 shows the results of the creep tests of monochlorotrifluoroethylene in three different degrees of crystallization. It was observed that the greatest creep occurred in the amorphous and the least in the crystalline. Both the time-independent (elastic) strains and creep strains were much larger in the amorphous. The total strain at a stress of 2700 psi after 500 hr under a constant load was 3.3, 2.8, and 1.5 per cent for the amorphous intermediate and crystalline, respectively. Recovery following creep of the amorphous and intermediate samples is also shown in Fig. 1.

Creep of the crystalline material is shown for four different stresses in Fig. 1. It was observed that creep at the stress of 3600 psi was much greater than would be expected from the creep of the crystalline material at lower stresses.

Examination of the specimens disclosed that crazing occurred in the crystalline material at the stress of 3600 psi. It was not known whether crazing occurred in the lower stresses. This suggests that the larger creep in the sample tested at 3600 psi was probably due to the combination of crazing plus creep. In order to determine at what stress crazing started in the crystalline material, a creep test was performed in which the stress was increased at invervals from 1610 to 1910 to 2210 to 2510 psi. It was found that no crazing occurred until about 19 hr after the load was increased to 2210 psi. At this time the strain increased from 1.06 to 1.27 per cent. From this time on, a count was taken of the number of transverse crazing marks per inch. In 1 in. the number of marks increased in succeeding 24-hr periods from 7 to 15 to 125 to 130.

Crazing was not observed in the material of intermediate crystallinity, but slight crazing was observed on one side of the amorphous sample. Theory of crazing suggests that the greatest crazing should occur in the most crystalline material. Thus crazing of one side of the amorphous sample may indicate crystallization on one surface.

Results of two creep tests of polyvinylchloride at 4000 psi are shown in Fig. 2, together with recovery following removal of load. One of these specimens was prepared from the sheet of material as received from the molder. The other specimen was prepared from the same sheet with the same orientation, after the sheet of material had been annealed

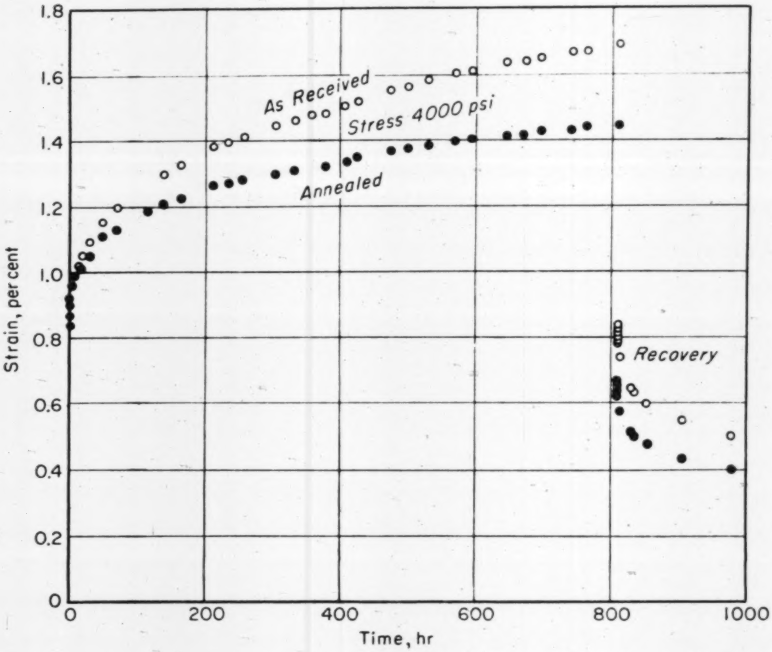

FIG. 2.—Creep Curves for Polyvinyl Chloride Before and After Annealing to Remove Residual Stresses—Temperature 77 F, Relative Humidity 50 per cent.

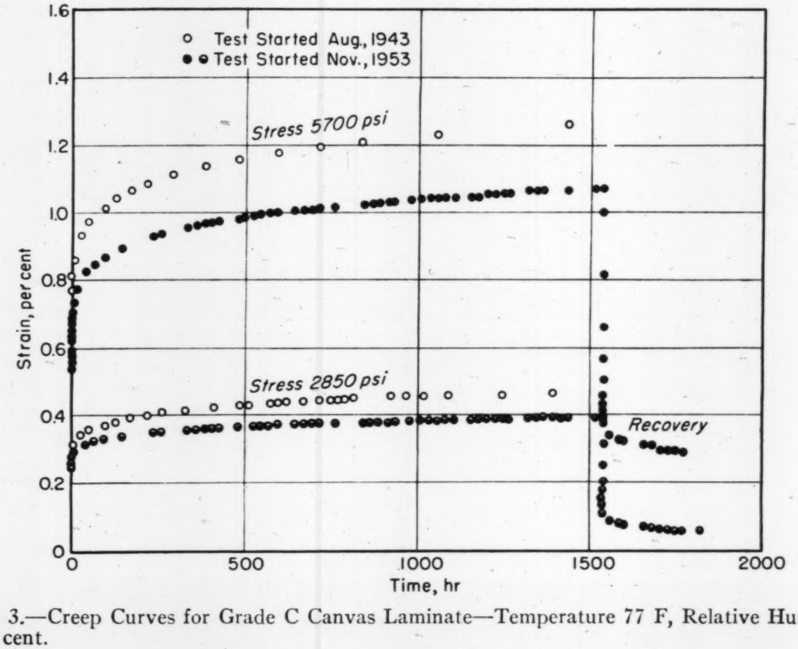

FIG. 3.—Creep Curves for Grade C Canvas Laminate—Temperature 77 F, Relative Humidity 50 per cent.

to remove residual stresses. The material was annealed by placing it on a glass plate and heating in an electric oven at 275 F for 15 min and cooling slowly. Measurement of reference marks on the surface before and after the annealing indicated a shrinkage of 5.1 and 0.8 per cent lengthwise and crosswise, respectively, of the original sheet (and direction of the calendering). Greater shrinkage at the center of the sheet than at the surface was indicated by the concave appearance of the edges of the sheet.

As shown in Fig. 2 the as-received sample showed more creep than the annealed sample, about 1.48 and 1.39 per cent creep, respectively. Apparently the tensile residual stresses locked in the sample made the material more susceptible to the action producing creep.

Creep tests at two different stresses are shown in Fig. 3 for a grade-C canvas laminate. The two tests shown at each stress were tested with an elapse of time of about 10 yr between tests. When tested in August, 1943, the laminate was about one month old. It has been stored at a constant temperature of 77 F and 50 per cent relative humidity continuously since that time except during machining of specimens.

The results shown in Fig. 3 indicate that the creep resistance has improved with age. The creep at 500 hr was reduced with age from 1.17 to 0.99 per cent at 5700 psi and 0.42 to 0.37 per cent at 2850 psi. Some of the possible causes of the improvement in creep resistance with age are further polymerization or cross-linking of the resin and loss of moisture content or other volatile constituents.

Conclusions:

1. Creep of monochlorotrifluoroethylene was markedly influenced by crystallinity. The most crystalline material was the most resistant to creep.
2. Crazing of monochlorotrifluoroethylene was found to result from creep. At the same stress the amorphous sample showed some crazing, intermediate samples showed none, and the crystalline samples crazed.
3. Creep produced crazing in the crystalline monochlorotrifluoroethylene in 19 hr at 2210 psi, and at 3600 psi considerable crazing was present.
4. When crazing occurred the creep strains were much larger than without crazing.
5. Residual tensile stresses in polyvinyl chloride resulted in greater creep.
6. Aging of grade-C canvas laminate produced a substantial reduction in creep.

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REFERENCES

(1) W. N. Findley, "Mechanical Tests of Cellulose Acetate-Part II on Creep," *Proceedings,* Am. Soc. Testing Mats., Vol. 42, p. 914 (1942).

(2) W. C. Ellis and J. D. Cummings, "Creep Test Method for Determining Cracking Sensitivity of Polyethylene Polymers," ASTM BULLETIN No. 178, Dec., 1951, p. 47 (TP 241).

(3) W. N. Findley, "Plastics: Their Mechanical Behavior and Testing," *Applied Mechanics Reviews,* Feb., 1953, pp. 49–53.

(4) W. N. Findley and W. J. Worley, "Mechanical Properties of Five Laminated Plastics," *Technical Note No. 1560,* Nat. Advisory Com. Aeronautics, Aug., 1948.

CREEP-TIME RELATIONS FOR NYLON IN TENSION, COMPRESSION, BENDING, AND TORSION*

By Joseph Marin,[1] A. C. Webber,[2] and G. F. Weissmann[3]

Synopsis

This paper presents the results of an investigation dealing primarily with the creep deformation - time relations of nylon FM 10001 and nylon FM 3001 under various types of stress. The stresses considered include tension, compression, pure bending, and pure torsion. For each of these stresses the influence of the stress magnitude upon the creep-time relations was investigated.

To determine if the creep deformation - time relations for torsion and bending could be predicted on the basis of the tension and compression creep-time relations, theoretical relations for torsion and bending creep were developed. These relations were based upon empirical equations defining creep deformation - time variations in tension and compression. A comparison of these theoretical creep-time relations for torsion and bending with the actual values showed good agreement between them.

Special creep tests were also made to evaluate the extent of creep recovery resulting on the removal of stress. It was found that a large part of the total creep strain was recovered on load removal. A series of tests was also conducted to determine the influence of rest periods upon the creep-stress-time relations. A small amount of creep recovery was found to occur during overnight rest periods between "cycling" tests.

In evaluating the suitability of materials such as plastics for various products and for structural and machine parts subjected to stresses, it is essential to consider the creep deformations produced. Creep deformations increase with time and may become so large as to make the member unserviceable, or they may become of such magnitudes as to produce fracture and failure of the member. The designer must select a design or working stress of such a value that the deformations are not excessive and that creep fracture is not probable in the estimated life of the part. The data used for selecting a design stress consist of a family of creep deformation - time curves for various constant stress values. From these data it is possible to obtain an empirical stress - creep deformation - time relation so that a design stress can be selected corresponding to a selected allowable creep deformation for a given assumed period of time. Although tensile stresses are ordinarily used as a basis for design, it is recognized that other stresses are usually present in most products and constructions. For this reason the present investigation is concerned primarily with the determination of creep deformation - time relations for various kinds of stresses including tension, compression, bending, and torsion. The creep-time data obtained for tension and compression are used to obtain empirical stress-creep-time relations. With these relations as a basis, theories are developed for obtaining both stresses and deformations in pure bending and torsion. These theoretically predicted values for bending and torsion are then compared with the actual test results obtained for specimens subjected to these stresses.

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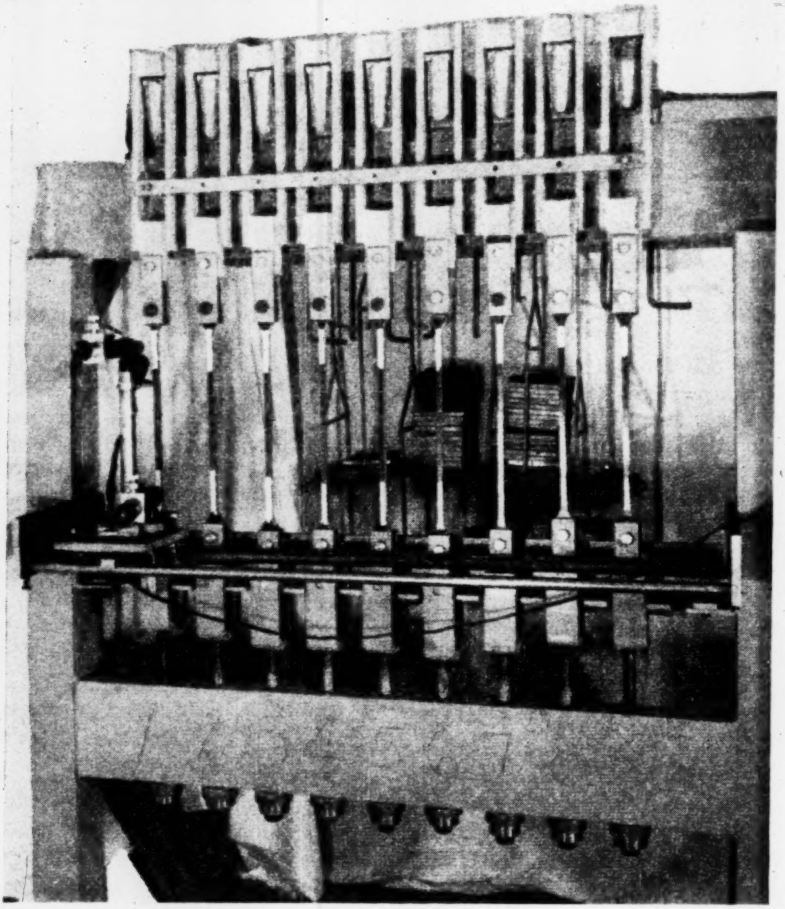
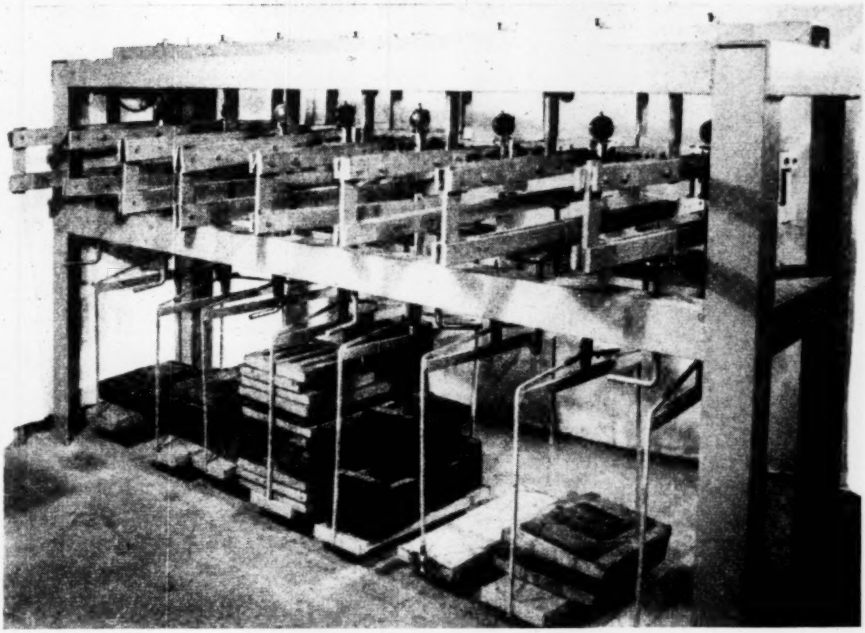


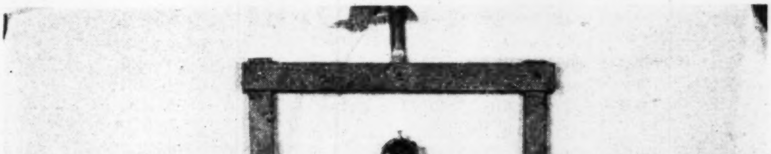
FIG. 1.--Tension Creep Testing Machine.

CREEP TEST RESULTS

The tests reported herein were made on nylons designated as FM 10001 and FM 3001. The specimens were molded and conditioned prior to testing. The creep tests for the nylon FM 10001 were made at a temperature of 77 ± 2 F and a relative humidity of 50 ± 2 per cent. For the nylon FM 3001 the temperature



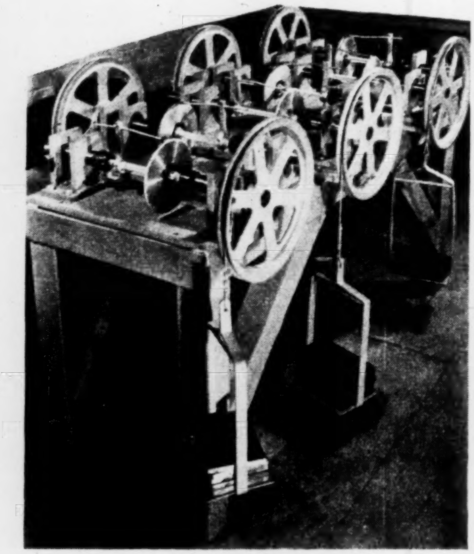
(*a*) Bending creep machine.



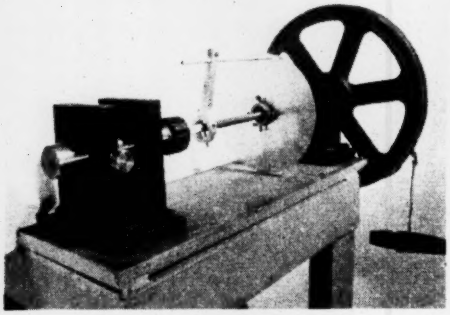
(*b*) Single bending creep unit.

FIG. 2.—Bending Creep Testing Apparatus.

was maintained at 73 ± 2 F with 50 ± 2 per cent relative humidity. The creep testing equipment for the tension, bending, and torsion creep tests is shown in Figs. 1, 2, and 3 and is described in reference (1).[4] Figure 4 shows a compression fixture for obtaining compression



(*a*) Torsion creep machine.



(*b*) Single torsion creep unit.

FIG. 3.—Torsion Creep Testing Apparatus.

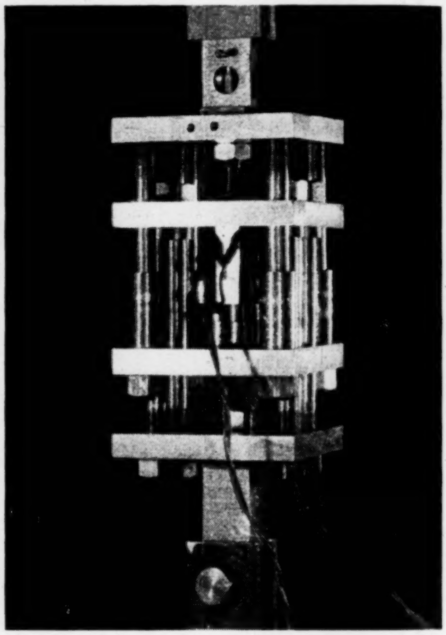


FIG. 4.—Compression Jig for Compression Creep Tests.

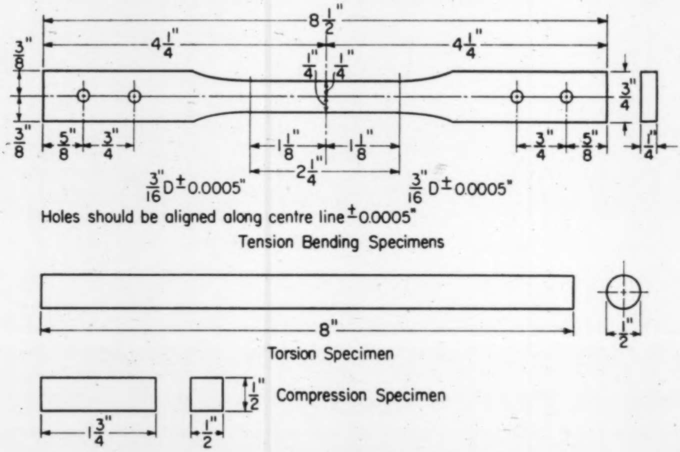

8 1/2"
4 1/4"
4 1/4"
1/4"
1/4"
3/8"
3/8"
3/4"
5/8"
3/4"
1 1/8"
1 1/8"
2 1/4"
3/4"
5/8"
1/4"
3/16" D ± 0.0005"
3/16" D ± 0.0005"
Holes should be aligned along centre line ± 0.0005"
Tension Bending Specimens
8"
1/2"
Torsion Specimen
1/2"
Compression Specimen
1 3/4"
1/2"

FIG. 5.—Dimensions of Specimens.

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[4] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 1329.

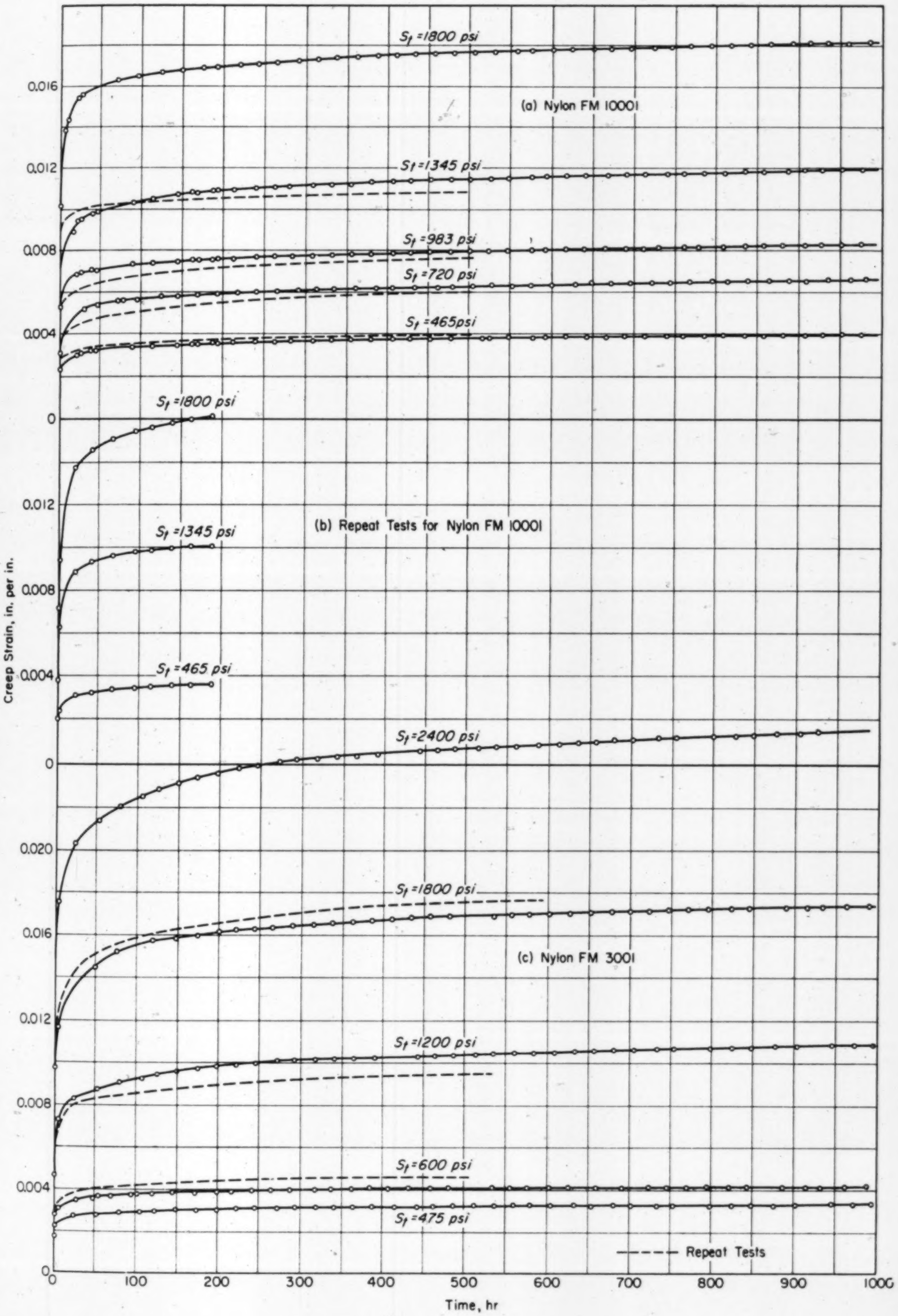

FIG. 6.—Tension Creep Curves.

creep using the tension creep testing machine. The dimensions of the specimens used for the various creep tests are shown in Fig. 5.

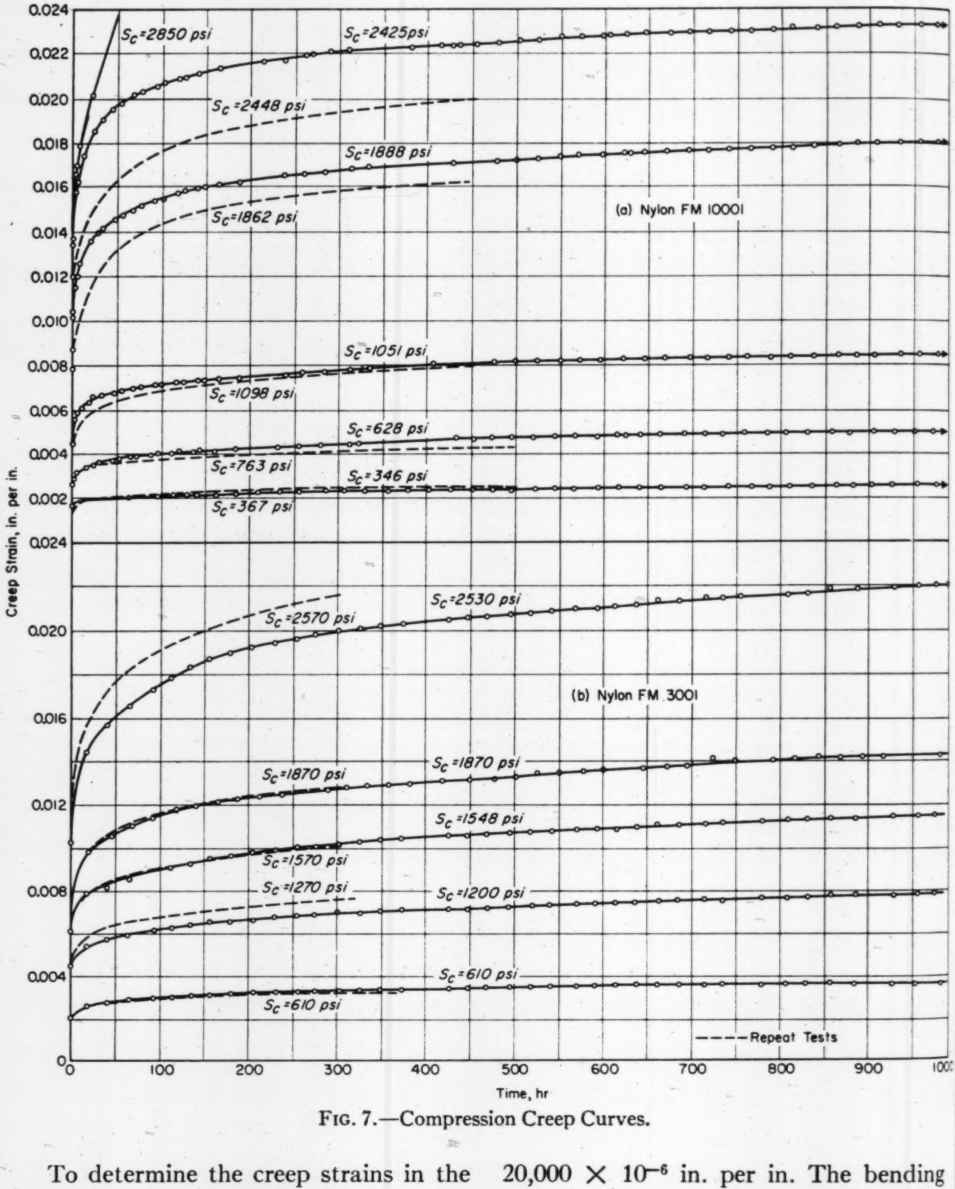

FIG. 7.—Compression Creep Curves.

To determine the creep strains in the tension and compression creep tests, SR-4 electric strain gages, type A-3, were used. Two gages were bonded on each specimen, one on each side to eliminate the effect of any eccentricity. The tension and compression gages had a sensitivity of 5×10^{-6} in. per in. and a range of $20{,}000 \times 10^{-6}$ in. per in. The bending creep strains were determined by means of A-12-4 type SR-4 strain gages cemented on the top and the bottom fibers of the specimens. These gages have the same sensitivity and range as the A-3 type gages mentioned above. The creep angle of twist was measured for a 4-in. gage length by a lightweight mechanical twist meter as described in reference (1). This twist meter has an unlimited range and a sensitivity of 0.05 deg per in. of gage length (equivalent to a strain of 20×10^{-6} in. per in.). Inaccuracies of the test equipment lead to errors of about $\pm\frac{1}{2}$ per cent in the stress, whereas variations in the specimen dimensions produce an error of about ± 1.5 per cent. It

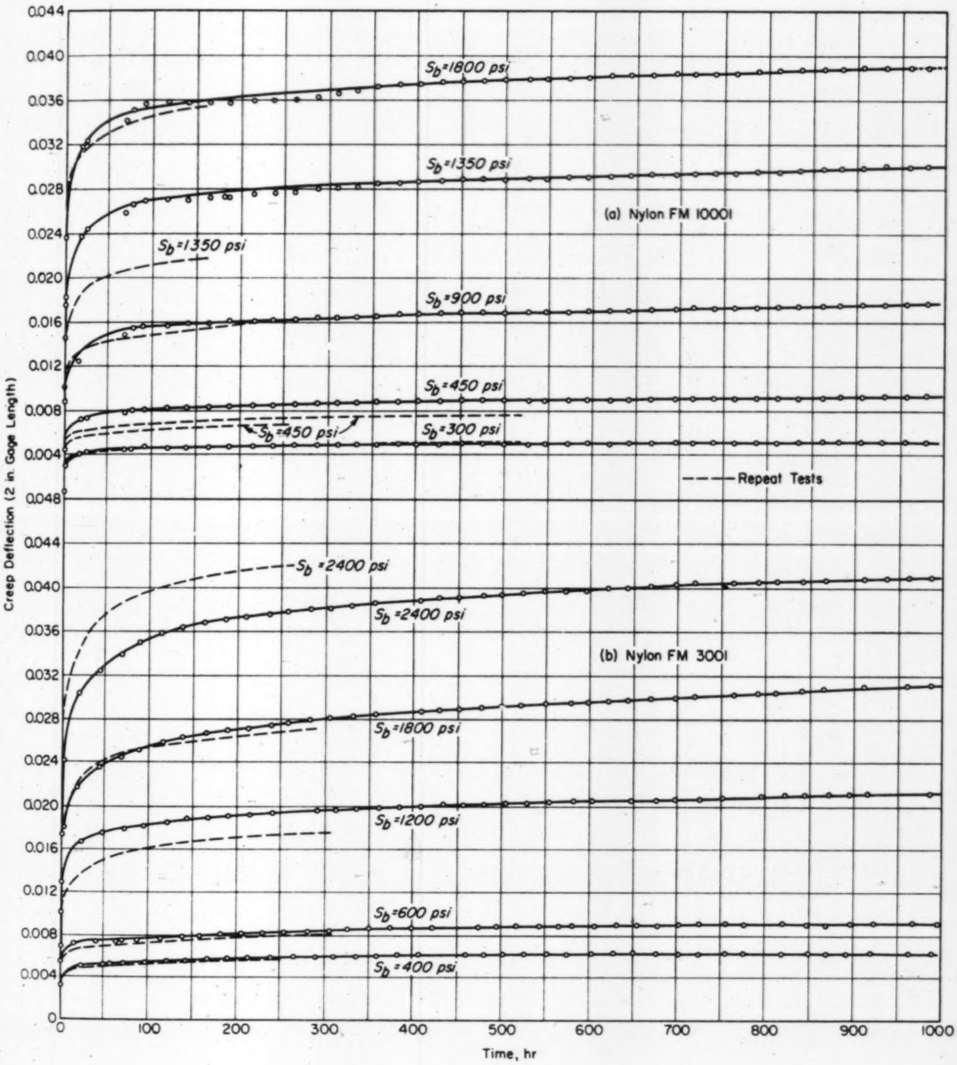

FIG. 8.—Bending Creep Curves.

is also estimated that the SR-4 strain gages tend to strengthen the gage section so the actual stress is about 3 per cent lower than the nominal stress. Deformation-time plots are shown in Figs. 6, 7, 8, and 9 for tension, compression, bending, and torsion, respectively. The repeat test results shown in the figures were obtained to determine the reproducibility of the test results.

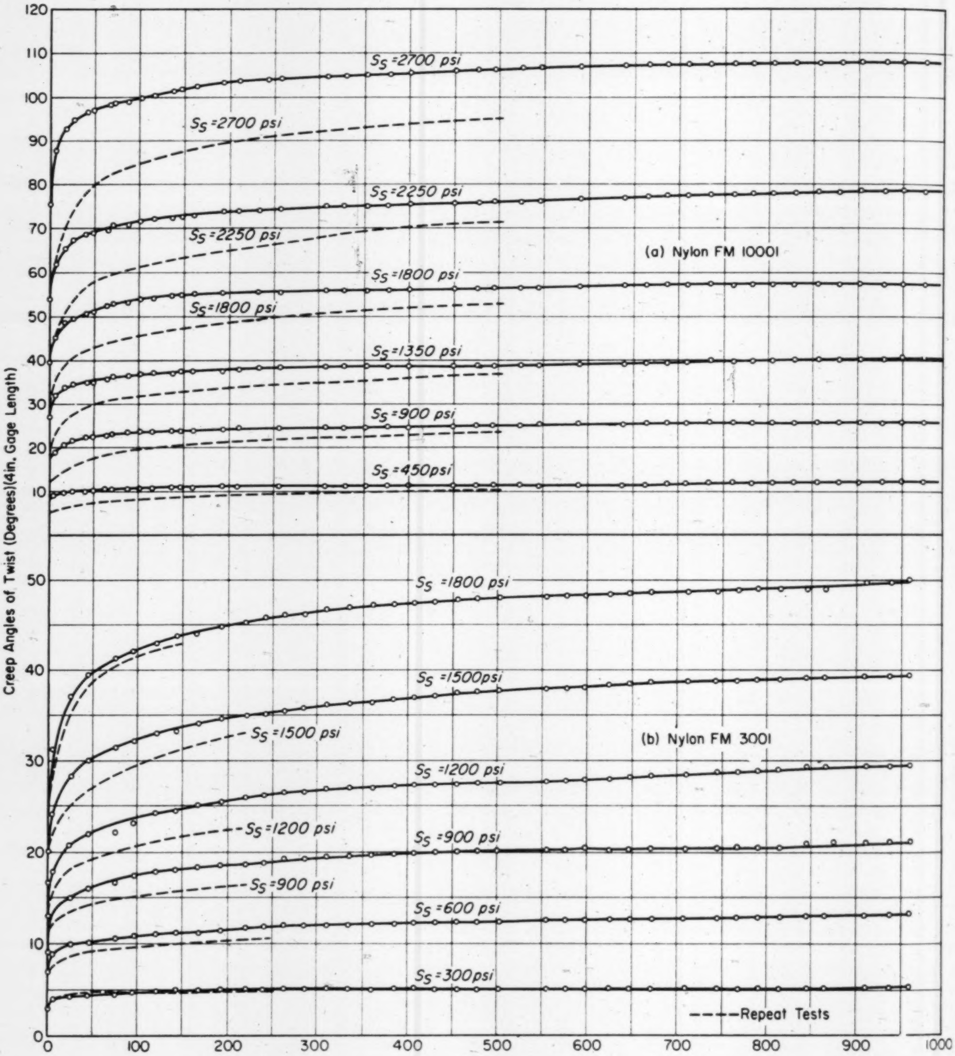

FIG. 9.—Torsion Creep Curves.

ANALYSIS OF TEST RESULTS

Interpretation of Tension and Compression Creep-Time Relations:

The creep-time relations shown in Figs. 6 to 9 indicate that, after the initial creep, the creep rate (or slope of the curve) remains essentially constant and may be assumed to be constant for all practical purposes.

To obtain an empirical equation relating the creep deformation, stress, and time, various methods of interpretations have been employed (3). In this study it was found that for long periods of time a creep-time curve *OAB* (Fig. 10) could be replaced by two straight lines *OD* and *DB* so that the creep strain is made up of the intercept strain *OD* and the time de-

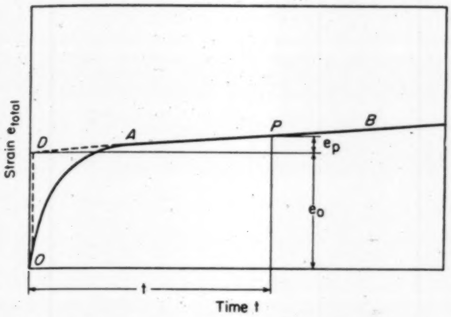

FIG. 10.—Assumed Creep-Time Relation.

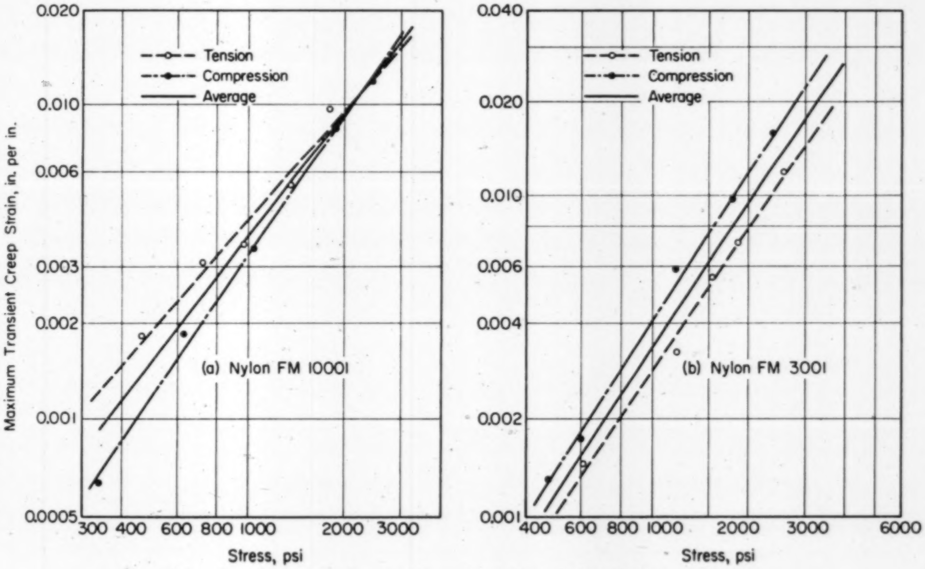

FIG. 11.—Log-Log Maximum Transient Creep Strain-Stress Relations.

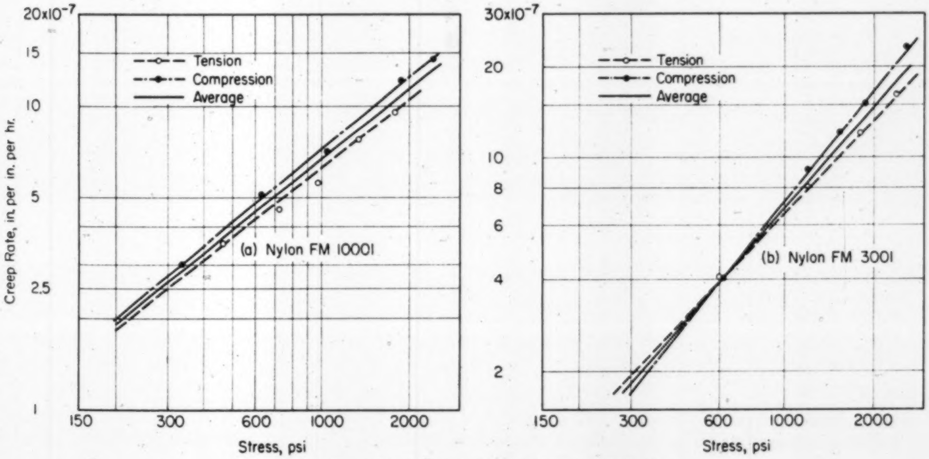

FIG. 12.—Log-Log Creep Rate Stress Relations.

TABLE I.—CREEP CONSTANTS FOR NYLON FM 10001 AND FM 3001.

$$e_{\text{total}} = e_e + e_p' + e_p'' = \frac{S}{E} + KS^{\alpha} + BS^{n}t$$

	Stress	K	α	B	n	E
Nylon FM 10001......	Tension	1.37×10^{-6}	1.16	3.41×10^{-9}	0.75	2.48×10^{5}
	Compression	0.12×10^{-6}	1.48	2.91×10^{-9}	0.79	2.53×10^{5}
	Average	0.45×10^{-6}	1.31	3.15×10^{-9}	0.77	2.50×10^{5}
Nylon FM 3001.......	Tension	8.29×10^{-8}	1.56	5.61×10^{-10}	1.02	2.74×10^{5}
	Compression	10.69×10^{-8}	1.47	1.77×10^{-10}	1.20	3.28×10^{5}
	Average	9.63×10^{-8}	1.52	3.15×10^{-10}	1.11	3.01×10^{5}

pendent strain $e_p'' = Ct$ where C is the creep rate and t is the time. The intercept strain OD is considered to be composed of the elastic strain and the maximum value of the transient creep strain (assumed to be developed instantaneously). Then the total strain is:

$$e = e_e + (e_p')_{\max} + e_p'' \quad \text{.......(1)}$$

where:

e_e = the elastic strain,

$(e_p')_{\max}$ = the transient creep strain, and

e_p'' = the time dependent strain = Ct.

It was also found that the strain $(e_p')_{\max}$ and creep rate C can be expressed approximately in terms of the stress by:

$$(e_p')_{\max} = KS^{\alpha} \quad \text{...........(2)}$$

and

$$C = BS^{n} \quad \text{............(3)}$$

where K, B, α, and n are experimental constants and S is the stress in tension or compression.

By taking the logarithm of both sides of Eqs 2 and 3, it is seen that these relations can be represented by straight lines on log-log plots. Figures 11 and 12 show the tension and compression test values for both the maximum transient creep strains and the creep rates. Straight lines representing these data, obtained by the method of least squares, are also shown in Figs. 11 and 12 for both tension and compression test results. The constants K, α, B, and n of Eqs 2 and 3 based on the foregoing straight lines are given in Table I. A comparison between the straight lines and test data in Figs. 11 and 12 shows that the experimental values of the maximum transient creep strains and creep rates are in good agreement with the values predicted by the average straight lines shown. In other words, the total strain, e, for either tension or compression can be determined by using Hooke's law and by placing values of $(e_p')_{\max}$ and C from Eqs 2 and 3 into Eq 1, or:

$$e = \frac{S}{E} + KS^{\alpha} + BS^{n}t \quad \text{........(4)}$$

For a time t and stress S the value e from Eq 4 gives the resultant unit strain.

Interpretation of Bending Creep-Time Relations:

The creep test results in Figs. 11 and 12 indicate that for the material tested the tension and compression creep behavior are approximately the same. It will therefore be assumed that for the tension and compression fibers in pure bending the maximum transient creep strain - stress relation is defined by the average straight line shown in Fig. 11, representing the average of the tension and compression relations. Similarly the minimum creep rate - stress relation is

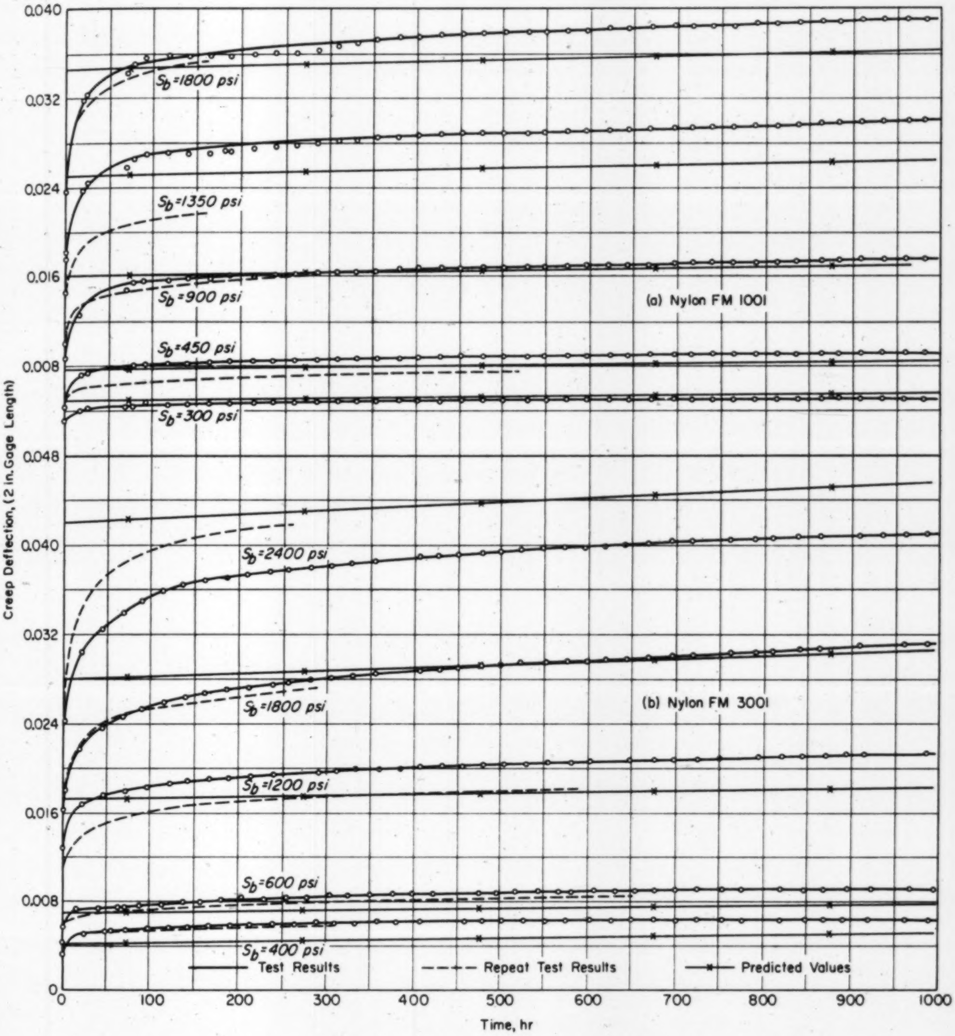

FIG. 13.—Comparison of Theoretical and Actual Creep Deflections in Bending.

TABLE II.—COMPARISON OF THEORETICAL AND ACTUAL BENDING CREEP DEFLECTIONS AT 1000 HR.

	Specimen	Bending Moment, M_b, in. lb	Elastic Stress, psi	Creep Deflections at 1000 hr, in.		Difference, per cent
				Experimental	Theoretical	
Nylon FM 10001.....	No. 1	3.34	300	0.0052	0.0054	−4
	No. 2	5.06	450	0.0094	0.0084	−11
	No. 3	9.57	900	0.0177	0.0172	−3
	No. 4	15.20	1350	0.0300	0.0276	−8
	No. 5	19.28	1800	0.0390	0.0364	−7
Nylon FM 3001......	No. 1	4.27	400	0.0063	0.00456	−27
	No. 2	6.41	600	0.0091	0.00766	−15
	No. 3	12.82	1200	0.0211	0.0182	−14
	No. 4	19.23	1800	0.0312	0.0306	−2
	No. 5	25.64	2400	0.0409	0.0456	+11

defined by the average straight line shown in Fig. 12. Then if S_b is the stress on the upper or lower outer fiber in the creep bending specimen, the value of the creep strain in either of these fibers will be assumed to be:

$$e = e_o + (e_p')_{max} + e_p''$$

$$= \frac{S_b}{E} + KS_b^{\alpha} + BS_b^{n} t \quad \text{..(5)}$$

where K, α, B, and n are the creep constants based on the average straight lines in Figs. 11 and 12.

Assuming that plane cross sections remain plane and that the deflections are small, it can be shown (3) that the deflection at mid-span of a specimen of length L subjected to a pure bending moment is:

$$w = \frac{L^2 e}{8h} \quad \text{............ (6)}$$

where e = the strain on the outer fiber.

From Eqs 5 and 6 the creep deflection at a time t can be determined as:

$$w = \frac{(L^2)}{8h}\left(\frac{S_b}{E} + KS_b^{\alpha} + BS_b^{n} t\right) \quad \text{.. (7)}$$

The stress S_b on the outer fiber is initially a function of both the time t and the moment M. After the initial stage, the creep rate becomes a constant and the stress in terms of the moment can then be shown to be equal to (3):

$$S_b = \frac{(Mh)}{2I}\,\frac{(2n+1)}{3n} \quad \text{....... (8)}$$

where I = the moment of inertia of the specimen cross section and h = the depth of the specimen. The theoretical creep deflection - time relations can now be determined by Eq 7 for a given value of the bending stress S as calculated by Eq 8. These theoretical creep deflection relations for the various values of moments M and corresponding stresses S, as determined on the basis of Eqs 8 and 7, are shown in Fig. 13. For the purpose of comparison, Fig. 13 also shows the actual test results. Table II gives a comparison between the actual and theoretical values of the creep deflections at 1000 hr. It also shows that the differences between these values at 1000 hr vary between 5 and 18 per cent depending upon the stress value used. In one isolated case for a nylon FM 3001 test at a low stress value, the discrepancy was 27 per cent. In view of the possible variations in the material, the agreement as indicated in Fig. 13 and Table II between test results and theory is considered very good.

Interpretation of Torsion Creep-Time Relations:

A theory for predicting the creep angle of twist in torsion based on tension and compression creep-stress-time relations has been developed by the authors (2, 4). It is based upon the creep-stress-time relation, $e = DS^m + BS^n t$, in place of that defined by Eq 4. A theory similar to that developed in reference (4) can be developed assuming the tension and compression creep-stress relations to be the same and to be defined by Eq 4. Then by this theory the angle of twist at a time t is defined by:

$$\theta = \frac{(L)}{r}\left[2\frac{(1+\nu)}{E}S_s + K(3)^{(\alpha+1)/2}S_s^{\alpha} + B(3)^{(n+1)/2}S_s^{n} t\right] \quad \text{.. (9)}$$

where:

S_s = the shear stress on the outer fiber,
L = the length of the member,
r = the radius,
v = Poisson's ratio, and
E = modulus of elasticity.

It can also be shown (4) that after the initial stage the shear stress S_s in terms of the applied torsional moment T becomes:

$$S_s = \left[\frac{(Tr)}{J}\right]\left[\frac{(3n+1)}{4n}\right] \quad \text{..... (10)}$$

where:

$J = \frac{\pi r^4}{2}$ = the polar moment of inertia of the cross section and

r = the radius of the cross section.

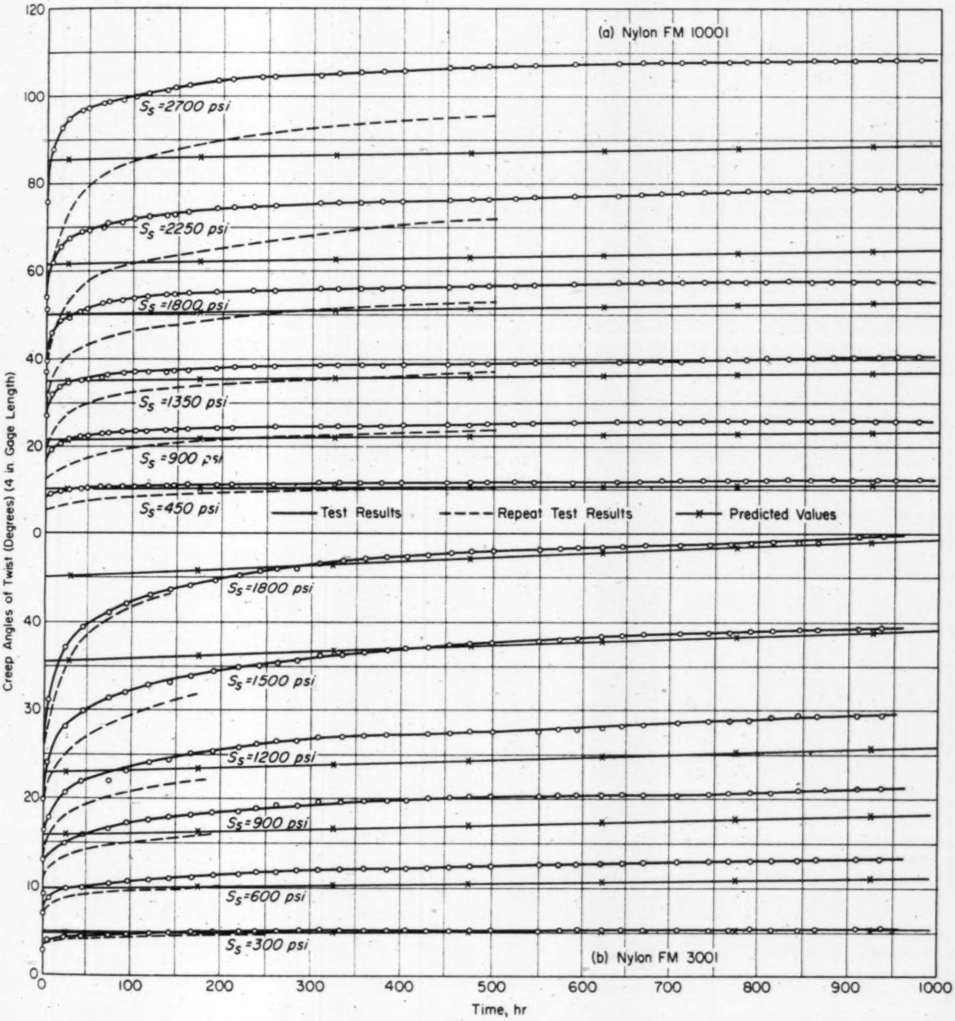

FIG. 14.—Comparison of Theoretical and Actual Creep Angles of Twist in Torsion.

The theoretical values of the creep angles of twist for a specimen subjected to a twisting moment T can now be obtained from Eqs 9 and 10. These theoretical creep angles of twist-time relations are also shown in Fig. 14 for the purpose of comparison with the test results. The percentage differences between the actual and theoretical angle of twist values at 1000 hr are listed in Table III. These results show that the maximum difference between theory and tests is about 27 per cent. Considering the influence of material variation, starting time differences between creep

TABLE III.—COMPARISON OF THEORETICAL AND ACTUAL CREEP ANGLES OF TWIST AT 1000 HR.

	Specimen	Twisting Moment, M_b, in. lb	Elastic Stress, psi	Creep Angles of Twist at 1000 hr, deg		Difference, per cent
				Experimental	Theoretical	
Nylon FM 10001.....	No. 1	9.38	450	11.5	10.9	−5
	No. 2	18.75	900	26.0	23.0	−11
	No. 3	28.13	1350	40.5	36.7	−9
	No. 4	37.50	1800	57.5	52.6	−9
	No. 5	46.88	2250	78.5	64.7	−18
	No. 6	58.25	2700	108.0	88.7	−18
Nylon FM 3001......	No. 1	7.59	300	5.4	5.1	−6
	No. 2	15.18	600	13.2	10.8	−22
	No. 3	22.78	900	21.1	17.8	−19
	No. 4	30.42	1200	29.3	25.5	−15
	No. 5	38.00	1500	39.4	38.9	−1
	No. 6	45.10	1800	49.9	49.1	−2

TABLE IV.—PERCENTAGE DIFFERENCES BETWEEN CREEP STRAINS WITH DIFFERENT STORAGE TIMES PRIOR TO TEST FOR NYLON FM 10001.

Type of Stress	Difference in Starting Time, hr	Average Difference in Creep Strain, per cent
Tension.............	160	−4
	360	−5
	500	−7
	1000	−8
Bending.............	360	−6
	1100	−15
Torsion.............	1080	−16

tests, and other factors, the agreement between theory and test is considered good.

REPRODUCIBILITY OF TEST RESULTS

Repeat tests for nylon FM 10001 shown plotted in broken lines in Figs. 6, 7, 8, and 9 all give consistently lower values of creep strains than the original. On the other hand, creep rates were reproducible. The increased resistance to creep as indicated by the decrease in creep strain in the repeat tests may be related to a change in the material or its moisture content occurring with time. Individual test results can thus be considered a function of the time elapsed between the initial molding of the speci-

TABLE V.—PERCENTAGE DIFFERENCES BETWEEN RESULTS OF DUPLICATE TESTS FOR NYLON FM 3001.

Type of Stress	Stress, psi	Creep Strains or Deformations at 200 hr		Difference, per cent
		Original Test	Repeat Test	
		in. per in.		
Tension.......	475	0.0030	0.0030	0
	600	0.0039	0.0044	−13
	1200	0.0098	0.0089	+7
	1800	0.0161	0.0166	−3
	2400	0.0237	...	...
Compression...	610	0.0031	0.0030	+3
	1200	0.0066	0.0072	−9
	1548	0.0097	0.0096	+1
	1870	0.0123	0.0124	−1
	2530	0.0192	0.0207	+5
		Deflection for 2-in. Gage Length, in.		
Bending.......	400	0.0029	0.0028	+3
	600	0.0041	0.0040	+3
	1200	0.0095	0.0085	+11
	1800	0.0135	0.0132	+2
	2400	0.0186	0.0207	−12
		Creep Angles of Twist for 4-in. Gage Length, deg		
Torsion.......	300	2.0	2.0	0
	600	4.6	4.1	+11
	900	7.4	6.5	+12
	1200	10.2	08.9	+13
	1500	13.8	13.1	+5
	1800	17.6[a]	17.1[a]	+3

[a] At 150 hr.

men and the starting time of the test. However, the difference between the creep strains of original and repeat tests is also a function of the difference between the two different times at which the tests were started.

Table IV gives the percentage discrepancy between creep strains obtained from identical tests that were started at different times.

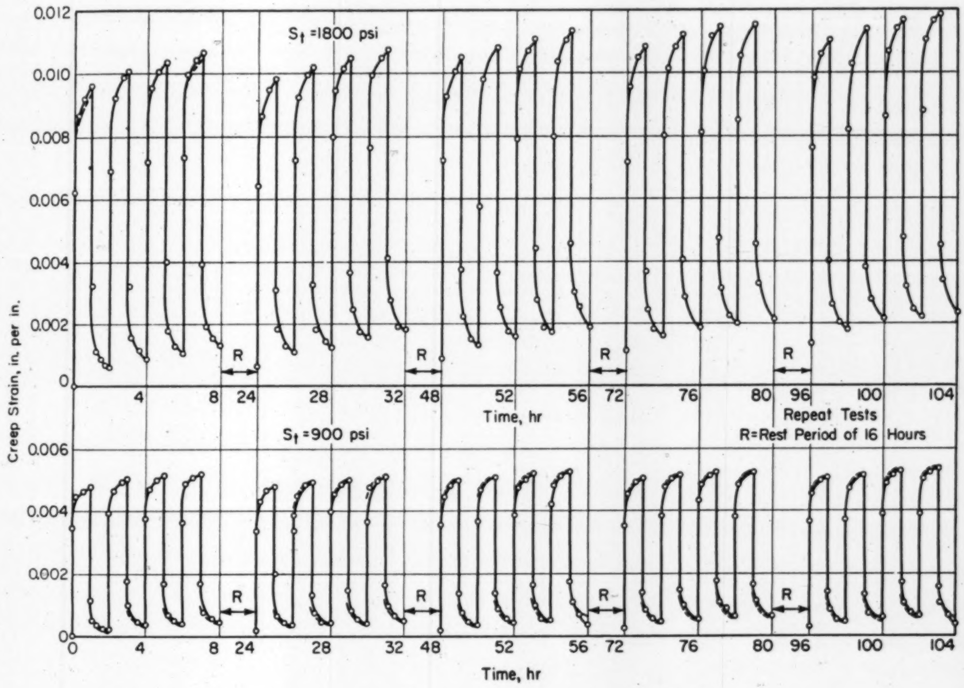

FIG. 15.—Tension Cycling Tests for Nylon FM 10001.

Repeat tests for nylon FM 3001 show some discrepancies between creep strains obtained from the original and repeat tests. These discrepancies are, however, distributed in a random manner and do not show any definite trend. This is perhaps due to the materials having been stored in the laboratory for a sufficiently long time so that the materials had arrived at states which are stable with respect to testing temperature and humidity conditions. The percentage discrepancies between creep strains obtained from the original and repeat tests for the two materials are listed in Table V.

CYCLING TESTS

For each of the materials herein investigated, creep and creep recovery of the material and the influence of rest periods on the creep-time relations were also investigated by applying a sequence of loading and unloading. Specimens were initially loaded at stress values corresponding to the constant stress creep tests, and creep strains were measured. The following sequence of loading and unloading was then used:

1. The load was removed after 1 hr and total creep strain measured.

2. With load removed creep recovery was measured for 1 hr.

3. The load was then applied for 1 hr.

4. The above loading and unloading

was repeated four times (or for a total elapsed time of 8 hr).

5. The specimen was then allowed to rest without load overnight for a period of 16 hr.

6. The foregoing pattern of loading and unloading was then repeated for five days.

Creep-time relations for tension, compression, bending, and torsion were obtained for each of the materials tested, using the loading cycles and rest periods outlined above. Figure 15 shows sample graphs representing some of the data obtained.

Test data show that in all cases a large portion of the creep strain was recovered with time after removal of load. At the end of each unloading cycle, not all the creep strain was recovered, but some remained. It is also observed that some creep recovery occurred during the overnight rest periods. It must be concluded, therefore, that not all the creep strain remaining at the end of each unloading cycle is of permanent nature. Presumably some portion of that creep strain could still be recovered if given sufficient time to do so. On the other hand, the creep strain remaining after the overnight rest period of 16 hr perhaps can be considered to be of permanent nature. Some of this type of strain is developed during each loading cycle, and the total magnitude of this permanent deformation increases with the number of loading cycles sustained by the material.

CONCLUSIONS

1. It was found that for the materials tested the creep deformation - time - stress relations for tension and compression can be expressed by:

$$e = \frac{S}{E} + KS^{\alpha} + BS^{n}t$$

where:

e = the creep strain,
S = the stress,
t = the time, and
K, α, B, and n = experimental constants.

2. Approximate theoretical creep deformation - time - stress relations in bending and torsion proposed in this paper agree well with the actual relations.

3. In the cases of nylon FM 10001, it was observed that the time elapsed between the time of molding the specimens and the starting time of the creep test has an influence on the test results. Up to a certain point, the greater this time the smaller the creep deformation. No such tendency was observed in the cases of nylon FM 3001, presumably because in the latter cases enough time had elapsed for the materials to reach conditions at equilibrium with the test conditions. The variability in the creep rates for nylon FM 10001 may also be due to the way this material was molded or annealed and to the moisture content.

4. The cycling tests made showed that a large part of the total creep strain can be recovered upon removal of load. This was found to be equally true for tension, compression, bending, and torsion. A certain amount of permanent strain was developed during each loading cycle, and the total magnitude of this permanent deformation increased with the number of loading cycles sustained by the material.

Acknowledgment:

The authors appreciate the advice and assistance of E. B. Cooper and other members of the Experimental Station of the E. I. du Pont de Nemours and Co., Inc., in planning this investigation. The study reported in this paper represents part of a project sponsored by the du Pont Co. The financial assistance given by the du Pont Co. to make possible this investigation is greatly appreciated.

REFERENCES

(1) Joseph Marin, Yoh-Han Pao, and George Cuff, "Creep Properties of Lucite and Plexiglass for Tension, Compression, Bending and Torsion," *Transactions*, Am. Soc. Mechanical Engrs., Vol. 73, No. 5, July, 1951, p. 705.

(2) Joseph Marin and Yoh-Han Pao, "Creep Relaxation Relations for Styrene and Acrylic Plastics," *Proceedings*, Am. Soc. Testing Mats., Vol. 51, p. 1277 (1951).

(3) Joseph Marin, "Engineering Materials," Prentice Hall Book Co. (1952).

(4) Joseph Marin and Yoh-Han Pao, "A Theory for Combined Creep Strain - Stress Relations for Materials with Different Properties in Tension and Compression," *Proceedings*, First National Congress of Applied Mechanics, Am. Soc. Mechanical Engrs., pp. 585–593 (1953).

DISCUSSION

MR. W. N. FINDLEY[1] (*by letter*).—The use of SR-4 strain gages cemented to the creep specimens as strain-measuring devices was noted in the paper. While there may be some greater ease of manipulation of this apparatus compared to optical-mechanical methods employed by the writer[2] or optical methods previously employed by the authors, it is not understood why the method was changed in veiw of some of the disadvantages of the SR-4 gage in this application. Some of these disadvantages are mentioned in the ASTM recommended practice for creep testing D 674 – 51 T.[3]

One of the disadvantages of the SR-4 gage for creep measurement was mentioned by the authors. It is that the gage carries some of the load applied to the specimen. The proportion of load taken by the gage probably varies somewhat from specimen to specimen due to variations in the cementing and stiffness of the paper base. Was the portion of load taken by the gage determined experimentally?

In addition to the effect on the stress, the restraining effect of the gage glued to the specimen may markedly retard creep in the region covered by the gage, thus yielding less creep than would otherwise occur. If experiments were performed to demonstrate that this factor was negligible for the material tested, it would add materially to the value of the paper if these data could be included.

It is known that gages cemented by the usual adhesives for room temperature applications are themselves subject to stress relaxation, the magnitude of which may be significant in long-time tests such as creep tests.

For some plastics it seems likely that the adhesive used to cement gages to the specimen could influence the creep behavior through solvent action, plasticizing action, diffusion, volumetric expansion due to absorption, etc. It would be of interest to know what adhesive was used in the present tests and whether its effect on creep of the material was investigated.

MR. ALBERT G. H. DIETZ[4] (*by letter*).—Stress-strain relationships in nylon and other high polymers are difficult to express in simple mathematical terms because of their combination of instantaneous elasticity, delayed elasticity, and permanent deformation. Time is an important consideration in these materials. When the strain levels at any given instant of time are not simply proportional to the stress levels, the problem becomes highly complex.

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[1] Professor of Engineering, Brown University, Providence, R. I.

[2] W. N. Findley and W. J. Worley, "Mechanical Properties of Five Laminated Plastics," *Technical Note No. 1560*, Nat. Advisory Comm. Aeronautics, Aug., 1948.

[3] Tentative Recommended Practice for Long-Time Creep or Stress Relaxation Tests of Plastics Under Tension or Compression Loads at Different Temperatures (D 674 – 51 T), 1952 Book of ASTM Standards, Part 6, p. 700.

[4] Acting Head, Building Engineering and Construction, Massachusetts Institute of Technology, Cambridge, Mass.

The expressions developed by the authors, although semi-empirical, have the virtue of simplicity while attempting to express the various modes of behavior of the polymer under stress over a period of time.

Several questions arise:

1. Can these expressions be rewritten in some inverse form to depict the relaxation behavior of the material, that is, the decay of stress with time at some fixed strain?

2. Can these expressions be used to depict creep recovery?

3. Can these expressions be rewritten to depict stress-strain behavior at various strain rates?

4. Materials undergoing creep may creep in a nearly linear fashion for some time and then begin to creep at an accelerating rate until fracture occurs. Did any of the specimens tested exhibit such behavior? Can the expressions given be used to depict such behavior?

SR-4 gages were bonded to the specimens. What adhesive was used? Was there any indication that localized solvent attack might alter the characteristics of the nylon in the vicinity of the gage?

MR. MERVIN B. HOGAN[5] (*by letter*).—Mr. Marin and his colleagues have again contributed, through the present paper, a most exemplary set of creep data, maintaining or exceeding the enviable standard of precision and excellence so ably set by Mr. Marin in all of his previous investigations of the creep of solids.

The primary concern of the writer has been the creep of solids subjected to direct stress; for that reason, his comments will be directed to the data of Figs. 6 and 7. These two figures present the data pertaining to the creep of nylon in tension and compression, respectively.

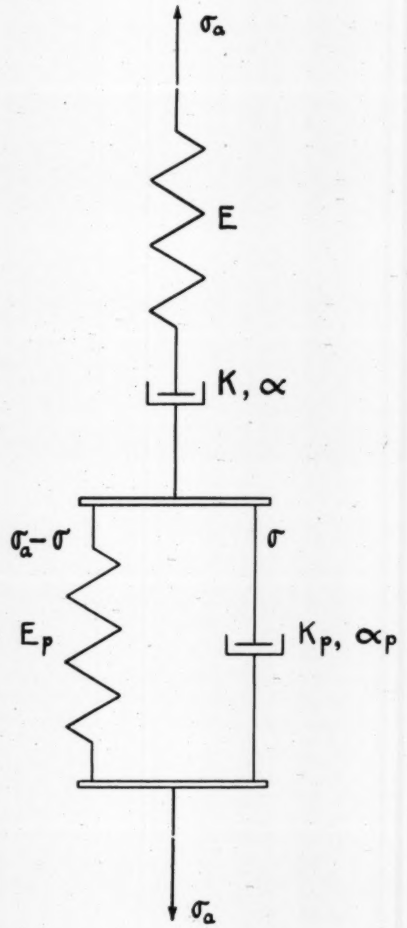

FIG. 16.—Four-Element Model Showing Schematic Representation of the Creep of a Solid.

The writer is obliged to Mr. Marin for graciously furnishing him a print from the original tracings, which eliminated

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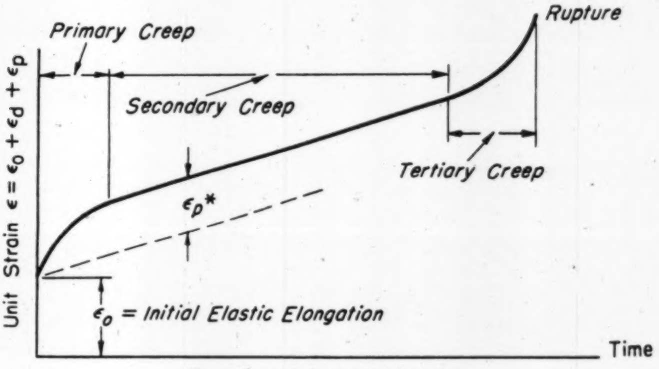
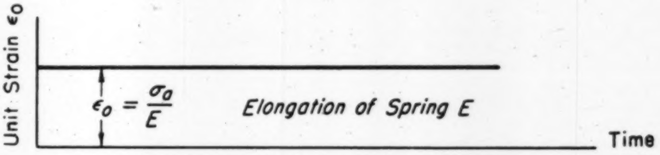
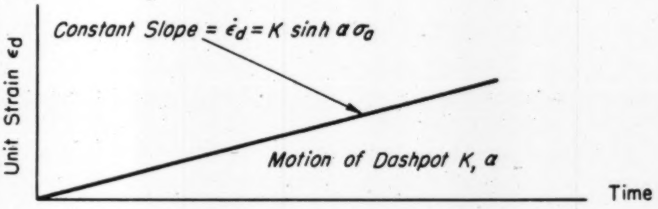
[5] Chairman, Department of Mechanical Engineering, University of Utah, Salt Lake City, Utah.



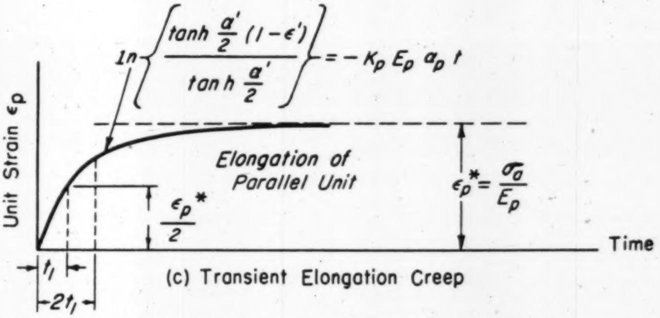
Experimental Creep Curve



(a) Initial Instantaneous Elastic Elongation



(b) Uniform Elongation Creep



(c) Transient Elongation Creep

FIG. 17.—Experimental Creep Curve and Its Resolution into Three Component Curves.

the necessity of photographing and enlarging the published cuts. In the case of the compression data, the curves supplied the writer differed slightly from those reproduced in Fig. 7.

A detailed analysis of these creep data for nylon in tension and compression from the standpoint of the absolute rate theory has been made by the writer. The details of this theory have been presented elsewhere (**5, 6, 7, 8**).[6]

The creep of the solid may be schematically represented by the four-element model shown in the accompanying Fig. 16. Neglecting the tertiary creep of Fig. 17, since it is of limited or no engineering interest, the general experimental creep curve there shown can be resolved into the three component curves indicated in Fig. 17(*a*, *b* and *c*). The physical relationship of these three curves to the model is clearly indicated by the notation of the several parameters.

Upon application of the stress σ_a there is an instantaneous elastic elongation of the material which is represented in the model by the elastic elongation of the open spring *E*. This constant elongation is graphically represented by Fig. 17(*a*). With the elapse of time, the open dashpot K, α, in series with the spring E, slips at a constant rate of elongation as shown in Fig. 17(*b*), while simultaneously the parallel unit composed of the spring E_p and the dashpot K_p, α_p elongates at a variable rate which is referred to as the "transient creep" component of the creep action. This is illustrated in Fig. 17(*c*).

The constants of a dashpot are here denoted by K and α. The constant K specifies the rate of flow of the dashpot and is expressed in reciprocal seconds, while α denotes the response, or resistance, of the element to stress and has the units of reciprocal pounds per square inch.

With the model in mind as an analogue, the analysis of the creep is readily undertaken. Let E be the spring modulus of the open spring (which is the usual modulus of elasticity of the material) and E_p represent the like property of the parallel spring. Further let

σ_a = stress applied to the four-element model in psi,

σ = stress acting on the parallel viscous element, and

$\sigma_a - \sigma$ = stress acting on the parallel elastic element.

The open elastic element E experiences a unit strain ϵ_0 due to the applied stress σ_a:

$$\epsilon_0 = \frac{\sigma_a}{E} \quad \text{(1)}$$

The rate of flow of the open dashpot is given by the hyperbolic sine law as[7]

$$\frac{d\epsilon_d}{dt} = \dot{\epsilon}_d = K \sinh \alpha\sigma_a \quad \text{(2)}$$

where:

$$K = 2\,\frac{V_h kT}{V_d h}\, e^{-\Delta F\ddagger/RT} \quad \text{(3)}$$

$$\alpha = \frac{V_h}{2kT} \quad \text{(4)}$$

The steady-state condition of the two open elements subjected to *constant stress* is specified by Eqs 1 and 2.

The two parallel units constituting the transient element each experience the same unit strain at any moment, or:

$$\frac{d\epsilon_p}{dt} = \dot{\epsilon}_p = \frac{1}{E_p}\,\frac{d(\sigma_a - \sigma)}{dt} = K_p \sinh \alpha_p\sigma \quad \text{(5)}$$

where:

$$K_p = 2\,\frac{V_{hp} kT}{V_{dp} h}\, e^{-\Delta F\ddagger/RT} \quad \text{(6)}$$

$$\alpha_p = \frac{V_{hp}}{2kT} \quad \text{(7)}$$

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[6] **The boldface numbers in parentheses refer to the list of references appended to this discussion, see p. 1343.**

[7] For derivation see pp. 3–22 of an earlier paper by the discusser (**8**).

Since σ_a is constant, Eq 5 may be written:

$$\frac{d\sigma}{\sinh \alpha_p \sigma} = -K_p E_p \, dt \ldots\ldots\ldots (8)$$

which is readily integrated with the result

$$\ln \tanh \frac{\alpha_p \sigma}{2} = -K_p E_p \alpha_p t + C.$$

But,

$$\sigma_a - \sigma = E_p \epsilon_p\,, \quad \text{or} \quad \sigma = \sigma_a - E_p \epsilon_p$$

and the relation becomes

$$\ln \tanh \frac{\alpha_p}{2} (\sigma_a - E_p \epsilon_p) = -K_p E_p \alpha_p t + C . (9)$$

or

$$\tanh \frac{\alpha_p}{2} (\sigma_a - E_p \epsilon_p) = e^{-K_p E_p \alpha_p t + C} \ldots (10)$$

The unit strain ϵ_p is that of the transient unit, so that when

$$t = 0, \quad \epsilon_p = 0$$

and the integration constant C is evaluated as

$$\ln \tanh \frac{\alpha_p \sigma_a}{2} = C \ldots\ldots\ldots (11)$$

If the maximum value attained by ϵ_p is denoted as $\epsilon_p{}^*$, then when

$$t = \infty, \quad \epsilon_p = \epsilon_p{}^*,$$

and Eq 10 yields

$$\tanh \frac{\alpha_p}{2} (\sigma_a - E_p \epsilon_p{}^*) = 0$$

or

$$E_p = \frac{\sigma_a}{\epsilon_p{}^*} \ldots\ldots\ldots\ldots (12)$$

The elimination of the constant C from Eqs 9 and 11, and the substitution of the value for E_p of Eq 12 give the result

$$\ln \left\{ \frac{\tanh \dfrac{\alpha_p \sigma_a}{2} \left(1 - \dfrac{\epsilon_p}{\epsilon_p{}^*}\right)}{\tanh \dfrac{\alpha_p \sigma_a}{2}} \right\} = -K_p E_p \alpha_p t . (13)$$

The variation as a function of time of the unit strain ϵ_p of the parallel or transient unit for the constant stress σ_a is expressed by this last relation.

The total unit strain ϵ at any time t, due to the constant stress σ_a, is the sum of the unit strains of the three elements, that is,

$$\epsilon = \epsilon_0 + \epsilon_d + \epsilon_p .$$

The constant K_p of the transient element is readily determined by Eq 13 if the following arbitrary condition is selected for the transient creep curve when

$$t = t_1\,, \quad \epsilon_p = \frac{\epsilon_p{}^*}{2},$$

which gives

$$K_p = \frac{1}{E_p \alpha_p t_1} \ln \frac{\tanh \dfrac{\alpha_p \sigma_a}{2}}{\tanh \dfrac{\alpha_p \sigma_a}{4}} \ldots\ldots (14)$$

Further algebraic simplification is achieved by letting

$$\alpha' = \alpha_p \sigma_a,$$

$$\epsilon' = \frac{\epsilon_p}{\epsilon_p{}^*}, \text{ and}$$

$$t' = \frac{t}{t_1}.$$

The substitution of the value of K_p from Eq 14 in Eq 13, with the above notation, leads to

$$\ln \frac{\tanh \dfrac{\alpha'}{2} (1 - \epsilon')}{\tanh \dfrac{\alpha'}{2}} = t' \ln \frac{\tanh \dfrac{\alpha'}{4}}{\tanh \dfrac{\alpha'}{2}} \ldots (15)$$

This result can now be utilized in connection with the transient creep curve if the particular value of the ratio ϵ' corresponding to a specified value of the ratio t' is imposed. For this purpose let

$$t' = \frac{t}{t_1} = 2$$

and

$$\epsilon'' = \epsilon' \Big|_{t'=2} = \frac{\epsilon_p}{\epsilon_p{}^*}\Big|_{t=2t_1} \quad \ldots\ldots (16)$$

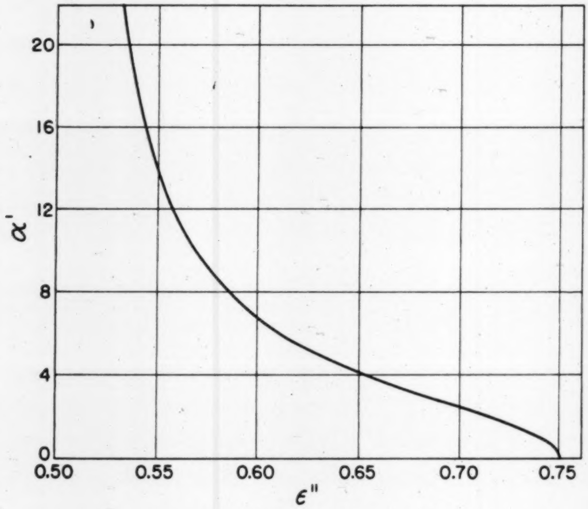

FIG. 18.—Plot of α' *versus* ϵ''.

Then Eq 15 becomes

$$\ln \frac{\tanh \frac{\alpha'}{2}(1 - \epsilon'')}{\tanh \frac{\alpha'}{2}} = 2 \ln \frac{\tanh \frac{\alpha'}{4}}{\tanh \frac{\alpha'}{2}} \quad \ldots (17)$$

This expression is of value in that α' *versus* ϵ'' may be plotted, as shown in Fig. 18, and the plot used to readily determine α' after the ratio ϵ'' at $t = 2t_1$ is evaluated from the transient creep curve. With α' known, the desired value of α_p follows from the previously specified ratio

$$\alpha_p = \frac{\alpha'}{\sigma_a} \quad \ldots\ldots\ldots\ldots (18)$$

With this value known, the associated constant K_p is readily calculated by Eq 14, which is conveniently written as

$$K_p = \frac{1}{E_p \alpha_p t_1} \ln \frac{\tanh \frac{\alpha'}{2}}{\tanh \frac{\alpha'}{4}} \quad \ldots\ldots (19)$$

The spring moduli E and E_p are determined directly by Eqs 1 and 12, respectively.

The only available relation pertaining to the constants K and α (Fig. 16) of the open dashpot is Eq 2. Consequently, they cannot be directly calculated from a single creep curve for one value of constant stress unless one of them is either known or assumed. However,

$$\sinh X = \frac{e^X - e^{-X}}{2},$$

and if exponent $-\alpha\sigma_a$ is considered negligibly small, Eq 2 becomes

$$\dot{\epsilon}_d = K \frac{e^{\alpha\sigma_a}}{2}$$

or

$$\ln \dot{\epsilon}_d = \ln \frac{K}{2} + \alpha\sigma_a \quad \ldots\ldots\ldots (20)$$

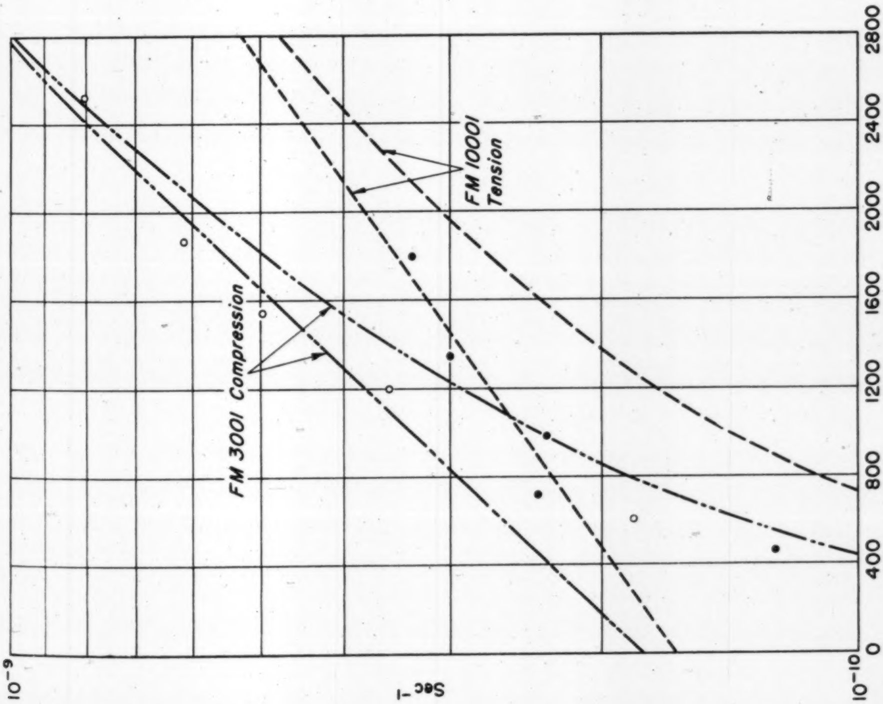

FIG. 19.—Creep Data for Nylon FM 3001 in Tension and Nylon FM 10001 in Compression.

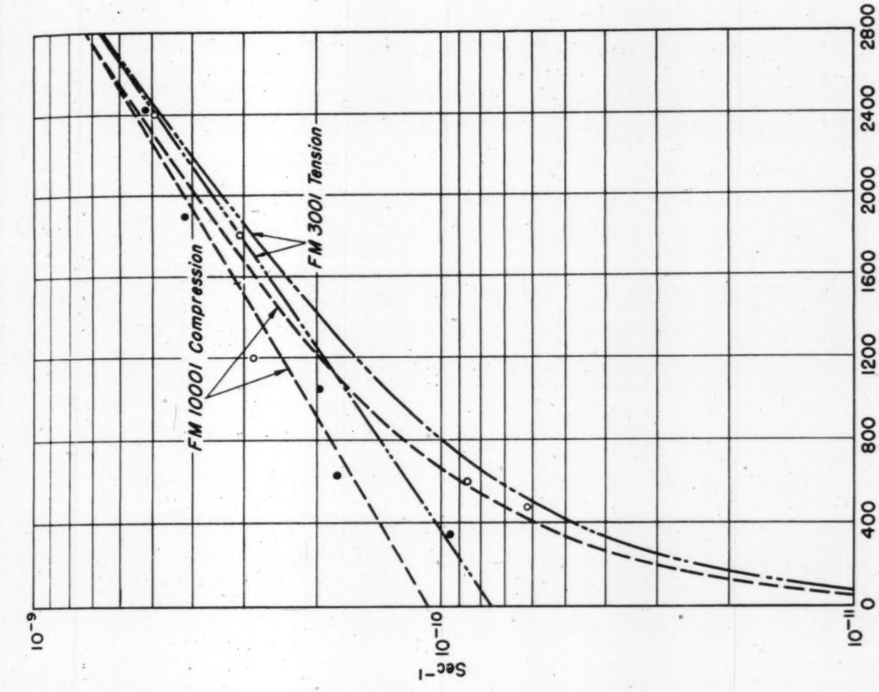

FIG. 20.—Creep Data for Nylon FM 3001 in Compression and Nylon FM 10001 in Tension.

Hence, if the logarithm of the creep rate at constant stress is plotted against the corresponding stress for each experimentally determined creep curve, the resulting curve is a straight line whose slope is α and whose intercept is $\frac{K}{2}$. In this manner these two constants are evaluated.

The calculation of the volume V_{hp} of Eq 7,

$$V_{hp} = 2k\alpha_p T,$$

and the activation energy $\Delta F_p\ddagger$ of Eq 6 possibly calls for a word of comment.

If Boltzmann's constant k is expressed in metric units as 1.38×10^{-16} ergs per deg Cent, and α_p is expressed in psi^{-1}, the latter quantity is readily converted to the metric system by the constant

$$1 \text{ psi}^{-1} = \frac{1}{6.89 \times 10^4}$$

reciprocal dynes per sq cm

The relation then has the numerical value

$$V_{hp} = 0.401 \times 10^{-20}\alpha_p T \ldots\ldots (21)$$

With the temperature T in degrees Centigrade and α_p in psi^{-1}, the volume V_{hp} is in cubic centimeters, which is readily expressed in cubic Ångstroms.

Assuming the ratio V_p to V_{dp} equal to unity, Eq 6 may be written in the form

$$e^{\Delta F_p\ddagger/RT} = \frac{2kT}{K_p h}$$

or

$$\frac{\Delta F_p\ddagger}{RT} = \text{nl}\,\frac{2kT}{K_p h}$$

or

$$\Delta F_p\ddagger = 2.303\ RT \log \frac{2kT}{K_p h}.$$

The substitution of the numerical constants

$R = 1.986$ cal per deg Cent,
$k = 1.38 \times 10^{-16}$ ergs per deg Cent, and
$h = 6.626 \times 10^{-27}$ erg-sec

results in the numerical relation

$$\Delta F_p\ddagger = 4.575T \log \frac{0.417 \times 10^{11} T}{K_p} \ldots (22)$$

where T is in degrees Centigrade and the logarithm is to the base 10.

The corresponding quantities V_h and $\Delta F\ddagger$ for the open element are also calculated by Eqs 21 and 22, respectively, as evidenced by Eqs 3 and 4.

From the authors' strain-time curves the writer ascertained the minimum creep rates to be of the magnitudes listed below:

Nylon FM 3001 in Tension

$\sigma_a = 475$ psi $\dot{\epsilon}_d = 6.11 \times 10^{-11}$ sec^{-1}
$\sigma_a = 600$ psi $\dot{\epsilon}_d = 8.61 \times 10^{-11}$ sec^{-1}
$\sigma_a = 1200$ psi $\dot{\epsilon}_d = 28.3 \times 10^{-11}$ sec^{-1}
$\sigma_a = 1800$ psi $\dot{\epsilon}_d = 30.8 \times 10^{-11}$ sec^{-1}
$\sigma_a = 2400$ psi $\dot{\epsilon}_d = 48.9 \times 10^{-11}$ sec^{-1}.

The values are plotted to a semilogarithmic scale in Fig. 19 and are indicated by the open circles.

Nylon FM 10001 in Tension

$\sigma_a = 465$ psi $\dot{\epsilon}_d = 12.5 \times 10^{-11}$ sec^{-1}
$\sigma_a = 720$ psi $\dot{\epsilon}_d = 23.6 \times 10^{-11}$ sec^{-1}
$\sigma_a = 983$ psi $\dot{\epsilon}_d = 23.1 \times 10^{-11}$ sec^{-1}
$\sigma_a = 1345$ psi $\dot{\epsilon}_d = 30.0 \times 10^{-11}$ sec^{-1}
$\sigma_a = 1800$ psi $\dot{\epsilon}_d = 33.1 \times 10^{-11}$ sec^{-1}.

These data are plotted to a semilogarithmic scale in Fig. 20 and are indicated by the solid circles.

Nylon FM 3001 in Compression

$\sigma_a = 610$ psi $\dot{\epsilon}_d = 18.3 \times 10^{-11}$ sec^{-1}
$\sigma_a = 1200$ psi $\dot{\epsilon}_d = 35.3 \times 10^{-11}$ sec^{-1}
$\sigma_a = 1548$ psi $\dot{\epsilon}_d = 49.5 \times 10^{-11}$ sec^{-1}
$\sigma_a = 1870$ psi $\dot{\epsilon}_d = 61.1 \times 10^{-11}$ sec^{-1}
$\sigma_a = 2530$ psi $\dot{\epsilon}_d = 80.0 \times 10^{-11}$ sec^{-1}.

The open circles of Fig. 20 denote these data.

Nylon FM 10001 in Compression

$\sigma_a = 346$ psi $\dot{\epsilon}_d = 9.45 \times 10^{-11}$ sec^{-1}
$\sigma_a = 628$ psi $\dot{\epsilon}_d = 17.8 \times 10^{-11}$ sec^{-1}
$\sigma_a = 1051$ psi $\dot{\epsilon}_d = 19.7 \times 10^{-11}$ sec^{-1}
$\sigma_a = 1888$ psi $\dot{\epsilon}_d = 41.7 \times 10^{-11}$ sec^{-1}
$\sigma_a = 2425$ psi $\dot{\epsilon}_d = 51.7 \times 10^{-11}$ sec^{-1}.

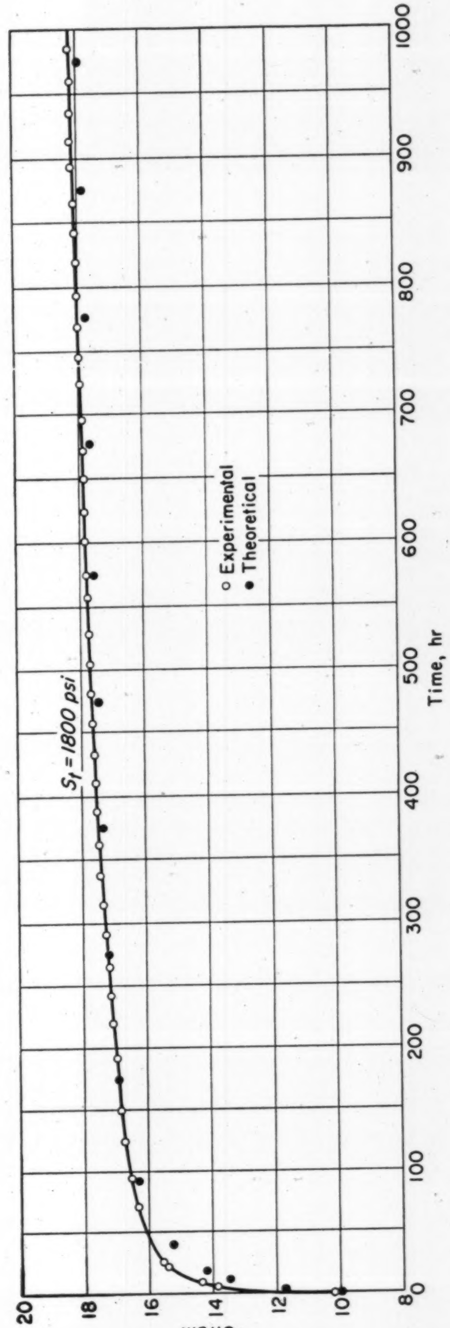

FIG. 21.—Creep-Time Curve for Nylon FM 10001 in Tension.

TABLE VI.—NYLON FM 10001 IN TENSION AT 25 C (77 F).

$\alpha = 0.416 \times 10^{-3}$ psi^{-1}, $K = 32.8 \times 10^{-11}$ sec^{-1}, $V_h^{1/3} = 8.01$ Å, $\Delta F\ddagger = 30{,}800$ cal

Stress, psi	E, psi	E_p, psi	t_1, hr	ϵ''	α'	α_p, psi^{-1}	K_p, sec^{-1}	$V_{hp}^{1/3}$, Å	$\Delta F_p\ddagger$, cal
465....	204×10^3	372×10^3	17.5	0.649	4.08	8.77×10^{-3}	111×10^{-11}	21.8	30 100
720....	238×10^3	258×10^3	10.5	0.646	4.20	5.83×10^{-3}	380×10^{-11}	19.1	29 300
983....	186×10^3	443×10^3	8.0	0.653	3.96	4.03×10^{-3}	467×10^{-11}	16.9	29 200
1345...	....	382×10^3	14.2	0.603	6.48	4.81×10^{-3}	80.0×10^{-11}	17.9	30 200
1800...	177×10^3	262×10^3	6.3	0.640	4.48	2.49×10^{-3}	1290×10^{-11}	14.4	28 600
Mean values calculated using the mean value of α'									
1063...	201×10^3	371×10^3	11.3	0.638	4.64	4.36×10^{-3}	270×10^{-11}	17.3	29 500
Mean values calculated using the mean value of ϵ''									
....	....	....	....	....	....	4.29×10^{-3}	285×10^{-11}	17.2	29 500

TABLE VII.—NYLON FM 3001 IN TENSION AT 23 C (73 F).

$\alpha = 0.779 \times 10^{-3}$ psi^{-1}, $K = 14.96 \times 10^{-11}$ sec^{-1}, $V_h^{1/3} = 9.75$Å, $\Delta F\ddagger = 31{,}200$ cal

Stress, psi	E, psi	E_p, psi	t_1, hr	ϵ''	α'	α_p, psi^{-1}	K_p, sec^{-1}	$V_{hp}^{1/3}$, Å	$\Delta F_p\ddagger$, cal
475......	286×10^3	334×10^3	5.7	0.641	4.40	9.25×10^{-3}	312×10^{-11}	22.3	29 400
600......	219×10^3	530×10^3	17.2	0.654	3.92	6.54×10^{-3}	114×10^{-11}	19.9	30 100
1200.....	261×10^3	227×10^3	5.4	0.615	5.72	4.77×10^{-3}	513×10^{-11}	17.9	29 200
1800.....	186×10^3	271×10^3	8.0	0.601	6.60	3.66×10^{-3}	249×10^{-11}	16.4	29 600
2400.....	....	218×10^3	7.7	0.596	7.00	2.91×10^{-3}	333×10^{-11}	15.2	29 400
Mean values calculated using the mean value of α'									
1295.....	238×10^3	316×10^3	8.8	0.621	5.53	4.27×10^{-3}	278×10^{-11}	17.2	29 500
Mean values calculated using the mean value of ϵ''									
....	....	....	....	....	....	4.17×10^{-3}	301×10^{-11}	17.1	29 500

These data are indicated by the solid circles in Fig. 19.

The straight line approximated by each of these sets of points was drawn as shown. Twice the intercept of the respective straight line on the ordinate axis gives the value of the parameter K of the series dashpot for the particular material. The slope of the straight line gives the value of the second parameter α relating to the series dashpot. With these values known, the magnitude of the uniform elongation creep of Fig. 17(b) is determined. The four creep rates were found to be:

FM 3001 in tension: $\dot{\epsilon}_d = 14.96 \times 10^{-11} \sinh 0.779 \times 10^{-3} \sigma_a$

FM 10001 in tension: $\dot{\epsilon}_d = 32.8 \times 10^{-11} \sinh 0.416 \times 10^{-3} \sigma_a$

FM 3001 in compression: $\dot{\epsilon}_d = 35.8 \times 10^{-11} \sinh 0.619 \times 10^{-3} \sigma_a$

FM 10001 in compression: $\dot{\epsilon}_d = 21.4 \times 10^{-11} \sinh 0.681 \times 10^{-3} \sigma_a$.

The curved lines of Figs. 19 and 20 are the respective plots of these four relations.

TABLE VIII.—NYLON FM 10001 IN COMPRESSION AT 25 C (77 F).
$\alpha = 0.681 \times 10^{-3}$ psi^{-1}, $K = 21.4 \times 10^{-11}$ sec^{-1}, $V_h^{1/3} = 9.31$Å, $\Delta F\ddagger = 31{,}000$ cal

Stress, psi	E, psi	E_p, psi	t_1, hr	ϵ''	α'	α_p, psi^{-1}	K_p, sec^{-1}	$V_{hp}^{1/3}$, Å	$\Delta F_p\ddagger$, cal
346....	206×10^3	640×10^3	31.9	0.667	3.44	9.94×10^{-3}	40.8×10^{-11}	22.8	30 600
628....	236×10^3	334×10^3	28.5	0.645	4.26	6.79×10^{-3}	90.5×10^{-11}	20.1	30 200
1051...	236×10^3	312×10^3	11.5	0.630	4.92	4.68×10^{-3}	259×10^{-11}	17.8	29 600
1888...	216×10^3	241×10^3	8.8	0.611	5.96	3.16×10^{-3}	400×10^{-11}	15.6	29 300
2425...	180×10^3	297×10^3	16.2	0.644	4.32	1.78×10^{-3}	664×10^{-11}	12.9	29 000
Mean values calculated using the mean value of α'									
1268...	268×10^3	365×10^3	19.4	0.639	4.58	3.61×10^{-3}	199×10^{-11}	16.3	29 700
Mean values calculated using the mean value of ϵ''									
....	....	....	....	....	....	3.58×10^{-3}	204×10^{-11}	16.2	29 700

TABLE IX.—NYLON FM 3001 IN COMPRESSION AT 23 C (73 F).
$\alpha = 0.619 \times 10^{-3}$ psi^{-1}, $K = 35.8 \times 10^{-11}$ sec^{-1}, $V_h^{1/3} = 9.04$Å, $\Delta F\ddagger = 30{,}700$ cal

Stress, psi	E, psi	E_p, psi	t_1, hr	ϵ''	α'	α_p, psi^{-1}	K_p, sec^{-1}	$V_{hp}^{1/3}$, Å	$\Delta F_p\ddagger$, cal
610....	311×10^3	580×10^3	17.8	0.695	2.56	4.20×10^{-3}	266×10^{-11}	17.1	29 600
1200...	273×10^3	550×10^3	24.5	0.665	3.52	2.94×10^{-3}	202×10^{-11}	15.2	29 700
1548...	254×10^3	419×10^3	23.2	0.635	4.72	3.05×10^{-3}	161×10^{-11}	15.4	29 800
1870...	....	399×10^3	22.7	0.623	5.28	2.82×10^{-3}	144×10^{-11}	15.0	29 900
2530...	246×10^3	281×10^3	22.5	0.595	7.08	2.80×10^{-3}	88.4×10^{-11}	15.0	30 200
Mean values calculated using the mean value α'									
1552...	271×10^3	446×10^3	22.1	0.643	4.63	2.98×10^{-3}	169×10^{-11}	15.3	29 800
Mean values calculated using the mean value ϵ''									
....	....	....	....	....	....	2.81×10^{-3}	202×10^{-11}	15.0	29 700

The results of the complete analysis of each of the four sets of the authors' data are tabulated in Tables VI, VII, VIII, and IX. The "mean values" calculated using the mean value of α' are in good agreement with those resulting from the mean value of ϵ''.

Using the mean values of the parameters of Table VI, theoretical points were calculated on the creep-time curve for the nylon FM 10001 in tension, subject to the applied stress of 1800 psi. In Fig. 21, is reproduced the authors' curve for this stress from Fig. 6, where the open circles denote their experimental points and the solid circles the theoretical points calculated by the writer.

The absolute rate theory provides a means of explaining the creep of solids in terms of the current concepts of atomic or molecular structure of materials. Fundamental progress in this field can only be achieved when a correlation is established between such theories of the solid state of matter and accurately determined experimental properties of the creep of solids.

Actually, the possible experimental accuracy yet attainable leaves room for considerable improvement. In the case of plastics, in particular, it is well known that unless well-aged specimens are used in the experimental tests there is little possibility of reproducing results.

The authors' candid discussion of the "reproducibility of test results" is most commendable. Few investigators reporting in the literature have seen fit to acknowledge this well-known difficulty. For plastics there is the other factor of a "change in the material" in addition to a change in the moisture content or a possible loss of volatiles. The change in the material is generally viewed by chemists as a very slow continuation of the polymerization process which was not fully completed during the manufacturing operation.

In Table X the writer has compiled the mean values of several parameters, as well as the resulting three-dimensional quantities V_h and V_{hp}, together with the activation energies $\Delta F\ddagger$ and $\Delta F_p\ddagger$, of some of the materials reported by Mr. Marin and his associates, as well as those of other investigators. Such a tabulation provides a ready comparison of results.

These values are closely related to the reproducibility of results. In any set of creep-time curves at several constant stresses, for any given material, there is some variation in the values of the parameters as evaluated from each creep-time curve. For that reason, the writer has utilized the mean values as the only feasible possibility of comparing magnitudes. A study of Table X will likely convince one that we still have quite a distance to go before we shall be able satisfactorily to explain our results from the standpoint of solid-state physics.

We must fully realize that a discussion of the creep in relatively very simple materials, such as metals which crystallize in the cubic system, is challenging both from the experimental and the theoretical aspects. In view of the fact that difficulties still exist in the investigations of these systems, we at once appreciate that the much more complex systems with which one deals in many practical problems are not yet amenable to complete treatment. This, of course, does not in any way reduce the value of such efforts, but does suggest that there is really no reason to be complacent with what has already been accomplished.

The examination of the crystalline nature of nylon made by Bunn and Garner (18) indicates that there are two crystalline modifications which exist in labile equilibrium at room temperature. While physical properties of these separate modifications have not been reported, it would be most unanticipated if they should be the same. These facts, together with the amorphous portions of the nylon, introduce complications which cannot now be treated.

Once we can get to a fuller appreciation and correlation of such theory and actuality, we may be able to attain the goal of all creep investigators, namely, the possibility of determining creep characteristics at ordinary temperatures from short-time creep-evaluations at elevated temperatures.

Those of us working in this field always welcome a new publication of creep data by Marin and his coworkers, knowing the quality of their results justifies extended study of the data.

TABLE X.—MEAN VALUES OF PARAMETERS AT 25 C (77 F) AND 1000 HR.

	Mean σ_a, psi	E, ps	α, psi^{-1}	K, sec^{-1}	$V_h^{1/3}$, Å	ΔF‡, cal	E_p, psi	t_1, hr	ϵ''	α'	α_p, psi^{-1}	K_p, sec^{-1}	$V_{hp}^{1/3}$, Å	ΔF_p‡, cal
Polystyrene (Lustrex LX)) **7, 12, 13**)[a]	3 070	480×10^3	1.33×10^{-3}	3.62×10^{-11}	11.7	32 100	$1\,330 \times 10^3$	25.4	0.648	3.97	1.29×10^{-3}	151×10^{-11}	11.6	29 800
Lucite in Tension (**7, 1**)	3 070	336×10^3	1.37×10^{-3}	3.00×10^{-11}	11.8	32 200	384×10^3	57.8	0.665	3.60	1.17×10^{-3}	298×10^{-11}	11.2	29 400
Plexiglas in Tension (**7, 1**)	3 260	453×10^3	0.896×10^{-3}	9.60×10^{-11}	10.2	31 400	583×10^3	41.4	0.647	4.23	1.30×10^{-3}	189×10^{-11}	11.6	29 700
Lucite in Compression (**7, 1**)	2 800	434×10^3	0.691×10^{-3}	15.8×10^{-11}	9.38	31 200	778×10^3	42.8	0.652	4.11	1.47×10^{-3}	128×10^{-11}	12.1	30 000
Plexiglas in Compression (**7, 1**)	3 120	416×10^3	0.650×10^{-3}	6.80×10^{-11}	9.00	31 700	$1\,020 \times 10^3$	10.6	0.600	7.02	2.25×10^{-3}	66.3×10^{-11}	13.9	30 300
Material L (**5, 14**)	4 630	767×10^3	0.815×10^{-3}	5.44×10^{-11}	9.92	31 800	767×10^3	43.5	0.681	3.02	0.653×10^{-3}	454×10^{-11}	9.21	29 200
Material AA (**5, 14**)	3 640	1910×10^3	0.285×10^{-3}	8.72×10^{-11}	7.01	31 600	$7\,700 \times 10^3$	31.3	0.693	2.59	0.711×10^{-3}	66.0×10^{-11}	9.20	30 400
Material CL (**5, 15**)	4 820	1120×10^3	0.568×10^{-3}	5.48×10^{-11}	8.23	31 900	$1\,080 \times 10^3$	44.3	0.657	4.73	0.980×10^{-3}	102×10^{-11}	10.3	30 200
Material C (**5, 15**)	5 650	1010×10^3	0.466×10^{-3}	9.00×10^{-11}	7.45	31 600	$2\,560 \times 10^3$	23.4	0.676	3.26	0.577×10^{-3}	257×10^{-11}	8.83	29 600
Material R (**5, 15**)	10 710	1450×10^3	0.191×10^{-3}	21.0×10^{-11}	4.77	31 100	$6\,460 \times 10^3$	17.8	0.678	3.21	0.300×10^{-3}	261×10^{-11}	7.06	29 500
Material P (**5, 15**)	11 830	3210×10^3	0.103×10^{-3}	16.84×10^{-11}	6.21	31 200	$8\,630 \times 10^3$	22.4	0.699	2.38	0.201×10^{-3}	316×10^{-11}	6.21	29 500
Material G (**5, 15**)	15 300	4480×10^3	0.128×10^{-3}	2.28×10^{-11}	5.35	32 400	$64\,000 \times 10^3$	14.8	0.639	4.67	0.305×10^{-3}	16.9×10^{-11}	7.13	31 200
Material PX (**5, 16**)	8 120	4130×10^3	0.113×10^{-3}	8.42×10^{-11}	5.14	31 600	$27\,600 \times 10^3$	33.2	0.658	3.96	0.488×10^{-3}	14.9×10^{-11}	8.36	31 200
Material CS (**5, 16**)	4 700	1380×10^3	0.348×10^{-3}	7.04×10^{-11}	7.46	31 700	$2\,470 \times 10^3$	25.5	0.669	3.44	0.732×10^{-3}	180×10^{-11}	9.57	29 800
Nylon FM 10001 in Tension	1 063	201×10^3	0.416×10^{-3}	32.8×10^{-11}	8.01	30 800	371×10^3	11.3	0.638	4.64	4.36×10^{-3}	270×10^{-11}	17.3	29 500
Nylon FM 3001 in Tension	1 295	238×10^3	0.779×10^{-3}	14.96×10^{-11}	9.75	31 200	316×10^3	8.8	0.621	5.53	4.27×10^{-3}	278×10^{-11}	17.2	29 500
Nylon FM 10001 in Compression	1 268	268×10^3	0.681×10^{-3}	21.4×10^{-11}	9.31	31 000	365×10^3	19.4	0.639	4.58	3.61×10^{-3}	199×10^{-11}	16.3	29 700
Nylon FM 3001 in Compression	1 552	271×10^3	0.619×10^{-3}	35.8×10^{-11}	9.04	30 700	446×10^3	22.1	0.643	4.63	2.98×10^{-3}	169×10^{-11}	15.3	29 800
Cellulose Acetate (**7, 9, 10**)	1 480	198×10^3	3.60×10^{-3}	2.30×10^{-11}	16.3	32 300	240×10^3	84.4	0.692	2.65	1.79×10^{-3}	309×10^{-11}	12.9	29 400
Unfilled Phenolic Resin (**7, 11**)	2 060	862×10^3	0.724×10^{-3}	3.28×10^{-11}	9.51	32 200	$5\,660 \times 10^3$	27.8	0.671	3.32	1.61×10^{-3}	34.4×10^{-11}	12.4	30 800
Woodflour Filled Phenolic (**6, 11**)	1 630	1180×10^3	1.55×10^{-3}	1.21×10^{-11}	12.3	32 400	$4\,740 \times 10^3$	11.0	0.602	6.61	4.06×10^{-3}	9.31×10^{-11}	16.9	31 600
Rag Filled Phenolic (**6, 11**)	1 610	1370×10^3	1.09×10^{-3}	4.14×10^{-11}	10.9	32 000	$4\,760 \times 10^3$	16.0	0.604	6.91	4.28×10^{-3}	5.22×10^{-11}	17.2	31 900
Cord Filled Phenolic (**6, 11**)	1 640	1170×10^3	0.810×10^{-3}	8.24×10^{-11}	9.88	31 600	$3\,350 \times 10^3$	13.0	0.598	7.50	4.58×10^{-3}	6.40×10^{-11}	17.6	31 800
Asbestos Filled Phenolic (**6, 11**)	2 440	1560×10^3	1.73×10^{-3}	0.352×10^{-11}	12.8	33 500	$6\,050 \times 10^3$	18.0	0.606	6.27	2.57×10^{-3}	8.27×10^{-11}	14.5	31 600
Mica Filled Phenolic (**6, 11**)	2 620	3100×10^3	1.19×10^{-3}	0.163×10^{-11}	11.3	35 300	$13\,530 \times 10^3$	5.5	0.642	4.41	1.69×10^{-3}	43.7×10^{-11}	12.6	30 700
Asbestos Filled Melamine (**6, 17**)	2 390	1700×10^3	0.737×10^{-3}	2.76×10^{-11}	9.58	32 300	$7\,280 \times 10^3$	8.8	0.604	7.27	3.04×10^{-3}	7.34×10^{-11}	15.4	31 600
Cellulose Filled Melamine (**6, 17**)	2 600	1120×10^3	0.544×10^{-3}	6.50×10^{-11}	8.65	31 700	$4\,690 \times 10^3$	14.6	0.620	5.60	2.03×10^{-3}	22.8×10^{-11}	13.4	31 000

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[a] **The boldface numbers in parentheses refer to the list of references appended to the paper and this discussion. The first number refers to the source of the writers' detailed analysis of the data, while the following numbers indicate the original sources of publication.**

MR. JOSEPH MARIN (*author's closure*).—Mr. W. N. Findley is concerned about the accuracy of measuring creep strains by the use of SR-4 gages. Tests were made in which the creep strain was determined both by micrometer microscopes and by SR-4 gages. It was found that the creep strain readings by these two methods were essentially the same—the percentage difference being negligible. As indicated by Mr. Findley, SR-4 gages cannot be used for some plastics because of the influence of the bonding material by the strain gage and the specimen. The load-carrying capacity of the SR-4 gage, compared to the specimen, was found to be negligible. In the tension creep tests, the percentage load carried by the gage, as determined by calculation, was about 3 per cent.

Mr. Dietz asked the question as to whether relaxation behavior can be predicted from the creep-time relation used. This can be done and agreement between the actual relaxation results and predicted theoretical values has been found to be good. However, creep-time curves, in which the creep rate accelerates prior to fracture, cannot be defined by the creep relations proposed in this paper. There was no indication that the bonding material used chemically attacked the nylon specimen in the vicinity of the strain gage.

The authors appreciate the kind comments made by Mr. Hogan regarding our investigation. Mr. Hogan proposes other expressions for defining the creep-stress-time relations and finds good agreement between test results and predicted values. Although it may be found that the absolute rate theory may provide a basic explanation of creep at the present time, it still remains a semi-empirical relationship for defining creep-stress-time relations. The choice between the relation proposed by Mr. Hogan and by the authors cannot be decided on the basis of one set of test results. However, the types of studies that have been made by Mr. Hogan, in the interpretation of creep data, are of great importance in the development of a mechanics of creep

REFERENCES

(5) Mervin B. Hogan, "The Engineering Application of the Absolute Rate Theory to Plastics: I—Laminates," *Bulletin No. 56*, Utah Engineering Experiment Station, University of Utah, Salt Lake City, Utah, August, 1951.

(6) Mervin B. Hogan, "The Engineering Application of the Absolute Rate Theory to Plastics: II—Filled Plastics," *Bulletin No. 58*, Utah Engineering Experiment Station, University of Utah, Salt Lake City, Utah, March, 1952.

(7) Mervin B. Hogan, "The Engineering Application of the Absolute Rate Theory to Plastics: III—Plastic Compounds," *Bulletin No. 59*, Utah Engineering Experiment Station, University of Utah, Salt Lake City, Utah, July, 1952.

(8) Mervin B. Hogan, "The Engineering Application of the Absolute Rate Theory to Plastics: IV—Miscellany," *Bulletin No. 62*, Utah Engineering Experiment Station, University of Utah, Salt Lake City, Utah, May, 1953.

(9) William N. Findley, "Mechanical Tests of Cellulose Acetate," *Proceedings*, Am. Soc. Testing Mats., Vol. 41, p. 1231 (1941); also *Modern Plastics*, Vol. 19, No. 1, Sept., 1941, p. 57.

(10) William N. Findley, "Mechanical Tests of Cellulose Acetate—Part II On Creep," *Proceedings*, Am. Soc. Testing Mats., Vol. 42, p. 914 (1942); also *Modern Plastics*, Vol. 19, No. 12, Aug., 1942, p. 71.

(11) David Telfair, T. S. Carswell, and H. K. Nason, "Creep Properties of Molded Phenolic Plastics," *Modern Plastics*, Vol. 21, No. 6, Feb., 1944, p. 137.

(12) J. A. Sauer, J. Marin, and C. C. Hsiao, "Creep and Damping Properties of Polystyrene," *Journal of Applied Physics*, Vol. 20, No. 6, June, 1949, p. 507.

(13) Joseph Marin and George Cuff, "Creep-Time Relations for Polystyrene Under Tension, Bending, and Torsion," *Proceedings*, Am. Soc. Testing Mats., Vol. 49, p. 1158 (1949).

(14) Joseph Marin, "Tension and Torsion Creep Properties of Cloth Laminates," ASTM BULLETIN, No. 143, Dec., 1946, p. 38.

(15) Joseph Marin, "Static and Dynamic Creep Properties of Laminated Plastics for Various Types of Stress," *Technical Note No. 1105*, Nat. Advisory Comm. Aeronautics, Feb., 1947.

(16) Joseph Marin and D. E. Hardenbergh, "Creep of Laminates in Tension, Bending, and Torsion," *Modern Plastics*, Vol. 26, No. 6, Feb., 1949, p. 101.

(17) D. Telfair, C. H. Adams, and H. W. Mohrman, "Creep, Long-Time Tensile and Flexural Fatigue Properties of Melamine and Phenolic-Plastics Materials," *Transactions*, Am. Soc. Mechanical Engrs., Vol. 69, p. 789 (1947); also *Modern Plastics*, Vol. 24, No. 9, May, 1947, p. 151.

(18) C. W. Bunn and E. V. Garner, "The Crystal Structures of Two Polyamides ('Nylons')," *Proceedings*, Royal Soc. (London) Vol. A189, p. 39 (1947).

TIME-TEMPERATURE RELATIONSHIP FOR RUPTURE STRESSES IN REINFORCED PLASTICS*

By S. Goldfein[1]

Synopsis

Proposed utilization of laminates fabricated from polyester resins reinforced with glass fibers in Corps of Engineers equipment which must sustain appreciable loads over relatively long periods of time has led to the investigation of the relationship between time, temperature, and rupture stresses in these materials. It was found that a time-temperature relationship developed for the study of rupture stresses in metals at elevated temperatures could be applied to these materials with considerable success. Application of this relation allows the use of short-time tests at elevated temperatures to determine long-time data at room temperature and allows the presentation of the complete rupture characteristics of a laminate on a single curve.

Materials fabricated from polyester resins reinforced with glass fibers have many desirable properties, foremost of which are their great specific strength and ease of handling. It is not surprising, therefore, to find that they are being used in items where only metals were considered heretofore. The Engineer Research and Development Laboratories at Fort Belvoir, Va., have been investigating the use of these laminates in such items as pontons, pipe for petroleum distribution, hot and cold water pipes, compressed gas cylinders, etc. Several of these items are currently under development. A number of them will operate under conditions of high temperature and stress for long periods of time once they are put into use.

Although there is an abundance of design information available regarding the properties of these materials, practically all of the data was obtained from tests which ran their course in a few minutes. Since the strengths of these materials are time-temperature dependent, short-time laboratory tests do not portray a complete picture of their capabilities. The purpose of this study was to investigate the relationship between time, temperature, and rupture stresses for these laminates.

A search of the literature disclosed only one pertinent report (**1**),[2] one that had been published by the United States Air Force. Stresses required to rupture plastics at various temperatures and rates of creep over periods of time up to 1000 hr were determined. The plastics were laminates fabricated from Plaskon 920, Stypol 16B, and Selectron 5003, reinforced with Owen-Corning Fabric 181-114. Unfortunately, the value of the work was limited to the stresses, temperatures, and periods of time used to perform the tests. An equation which related ultimate strengths to the duration of application of stress would be very useful. Several of these have been devised but are either too cumbersome or complicated, or contain constants or other factors difficult to determine. They are based on rate-process theories and take the same general form as:

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[2] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 1351.

$$t = Be^{EU/SRT} \text{ .... } (1)$$

where:

t = time for fracture,
B = constant,
e = natural logarithm,
E = Young's modulus,
U = activation energy,
S = ultimate tensile strength,
R = gas constant, and
T = absolute temperature

and:

$$r = Ae^{-QS/RT} \text{ .... } (2)$$

where:

r = rate,
A = constant, and
QS = activation energy for the process.

Holloman and Jaffe (2) have shown that the relation between tempering time and temperature for a given hardness derived from Eq 2 is expressed by the following equation:

$$T(C + \log t) = \text{constant} \text{ .... } (3)$$

TABLE I.—STRESS TO RUPTURE LAMINATES AND K VALUES.

Temperature, deg Fahr	Resin	Type Stress	Stress to Produce Rupture in 10 hr, psi	$K \times 10^{-3}$	Stress to Produce Rupture in 100 hr, psi	$K \times 10^{-3}$	Stress to Produce Rupture in 1000 hr, psi	$K \times 10^{-3}$
80......	Plaskon 920	Tension	29 600	11.3	29 300	11.9	29 100	12.4
200......	Plaskon 920	Tension	27 800	13.8	27 400	14.5	27 200	15.2
300......	Plaskon 920	Tension	25 600	16.0	25 100	16.7	24 000	17.5
400......	Plaskon 920	Tension	25 400	18.0	21 000	18.9	14 400	19.8
80......	Plaskon 920	Compression	26 800	11.3	23 000	11.9	19 000	12.4
300......	Plaskon 920	Compression	11 000	16.0	10 500	16.7	9 200	17.5
400......	Plaskon 920	Compression	5 300	18.1	4 400	18.9	3 500	19.8
80......	Stypol 16B	Tension	25 300	11.3	24 700	11.9	23 700	12.4
300......	Stypol 16B	Tension	24 800	16.0	24 000	16.7	23 200	17.5
500......	Stypol 16B	Tension	16 000	20.2	12 000	21.2	5 300	22.2
80......	Stypol 16B	Compression	24 200	11.3	33 000	11.9	22 600	12.4
300......	Stypol 16B	Compression	10 700	16.0	9 400	16.7	8 100	17.5
500......	Stypol 16B	Compression	3 800	20.2	2 700	21.2	1 400	22.2
80......	Selectron 5003	Tension	40 700	11.3	37 800	11.9	36 300	12.4
200......	Selectron 5003	Tension	28 900	13.8	28 200	14.5	27 300	15.2
80......	Selectron 5003	Compression	27 500	11.3	26 000	11.9	24 800	12.4
200......	Selectron 5003	Compression	7 200	13.8	6 000	14.5	4 900	15.2

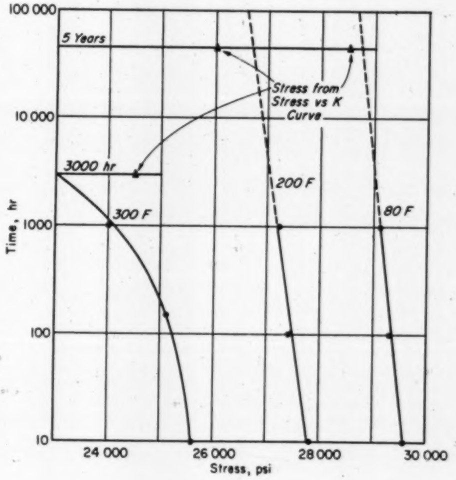

FIG. 1.—Stress to Produce Tension Rupture in Plaskon 920 Laminates.

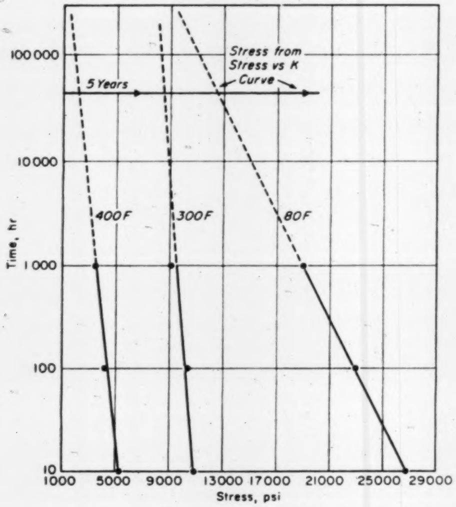

FIG. 2.—Stress to Produce Compression Rupture in Plaskon 920 Laminates.

Since both creep and tempering seem to obey rate-process laws, it was believed that this concept should be directly applicable in creep and rupture testing for the purpose of shortening the test time.

Larson and Miller, metallurgists employed by the General Electric Co., carried this relationship one step farther (3). They showed that for a given stress in steel and other metals the time to rupture is related to temperature by the equation:

$$T(20 + \log t) = K \text{ (constant)} \ldots\ldots (4)$$

where:

T = absolute temperature, deg Rankine, and

t = time, hr.

Their master curves for rupture stress *versus* K were plotted on semilogarithmic paper. These covered a temperature range from 500 to 1900 F. Examination of the curves revealed that the deviation of points from a single curve was small and was probably due to experimental

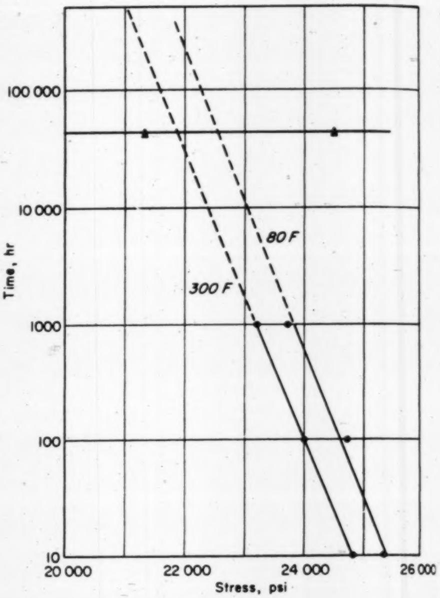

FIG. 3.—Stress to Produce Tension Rupture in Stypol 16B Laminates.

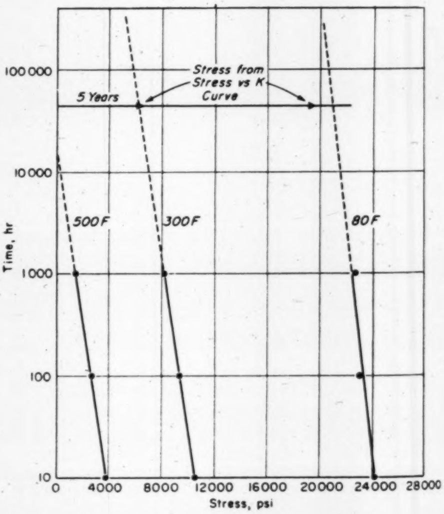

FIG. 4.—Stress to Produce Compression Rupture in Stypol 16B Laminates.

errors. Application of this relation allowed the use of short-time tests to determine long-time data with remarkable accuracy.

The value of 20 for C in Eqs 3 and 4 was developed both empirically and by derivation. An examination of the derivation showed that C for all intents and purposes was a constant almost independent of material. Thus it was conceivable that the formula would be applicable to plastic materials.

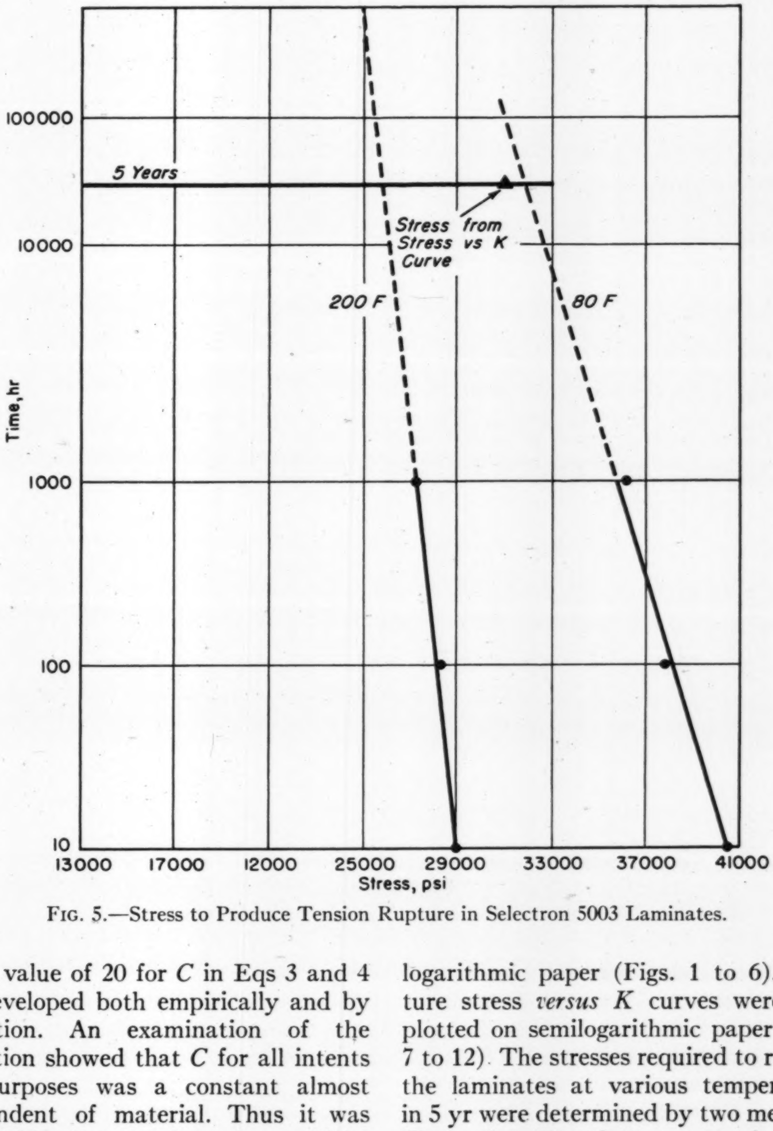

FIG. 5.—Stress to Produce Tension Rupture in Selectron 5003 Laminates.

The K values were calculated for all the laminates listed in the Air Force report (Table I). Time *versus* rupture stress curves were drawn on semilogarithmic paper (Figs. 1 to 6). Rupture stress *versus* K curves were then plotted on semilogarithmic paper (Figs. 7 to 12). The stresses required to rupture the laminates at various temperatures in 5 yr were determined by two methods. First, the K values were calculated, using the appropriate values for the

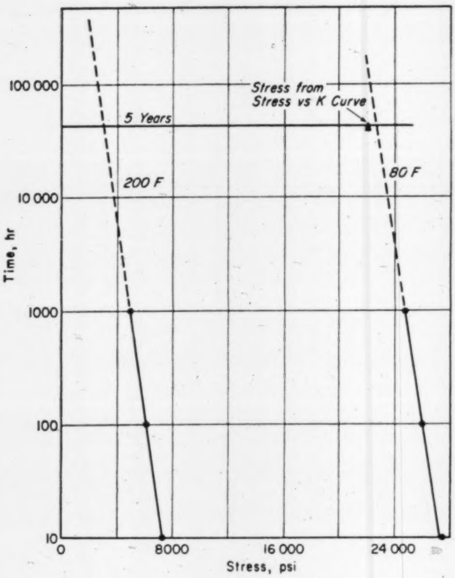

FIG. 6.—Stress to Produce Compression Rupture in Selectron 5003 Laminates.

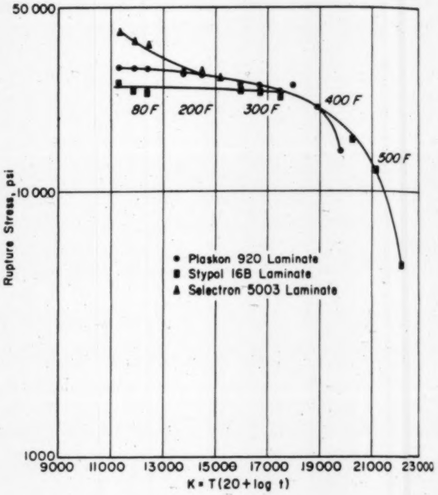

FIG. 7.—Stress to Produce Tension Rupture *versus K* Plaskon 920, Stypol 16B, and Selectron 5003 Laminates.

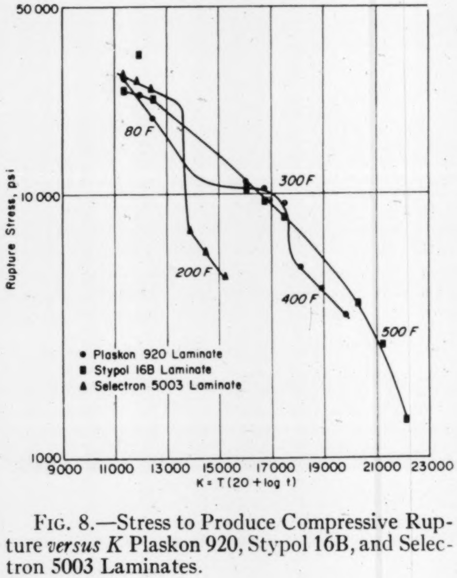

FIG. 8.—Stress to Produce Compressive Rupture *versus K* Plaskon 920, Stypol 16B, and Selectron 5003 Laminates.

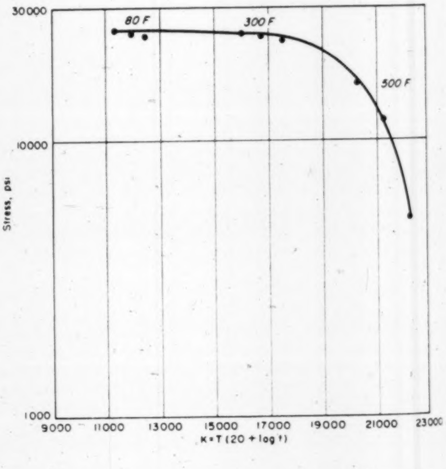

FIG. 9.—Stress to Produce Tension Rupture *versus K* Stypol 16B.

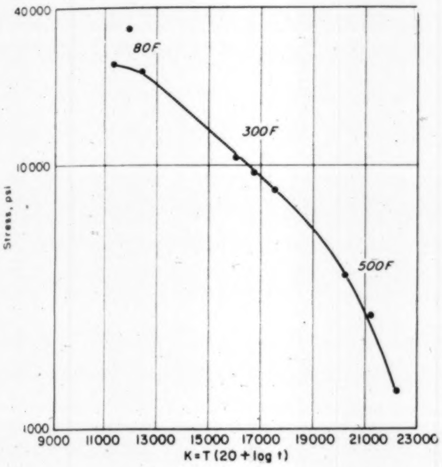

FIG. 10.—Stress to Produce Compressive Rupture *versus* *K* Stypol 16B.

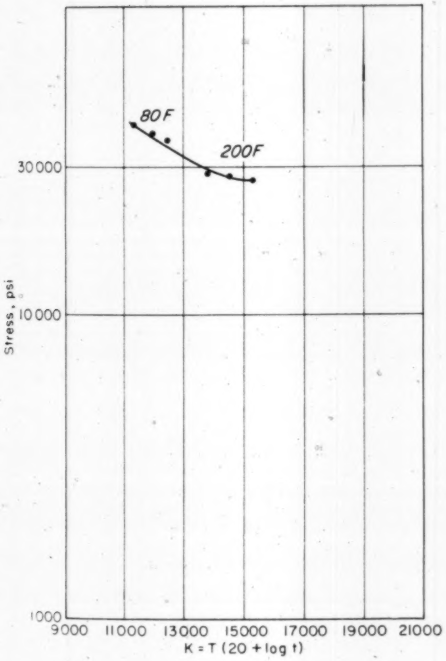

FIG. 11.—Stress to Produce Tension Rupture *versus* *K* Selectron 5003.

temperatures and time. The stresses were then noted on the rupture stress *versus* *K* curve. Secondly, the time *versus* rupture stress curves were extrapolated to a time of 5 yr and the corresponding stresses noted (Table II).

The stresses to rupture in 5 yr, as determined by both methods, were found to be in close agreement (within 10 per cent), with the exception of the results obtained from compressive tests on Plaskon 920 laminates. The latter were off approximately 20 per cent at 80 F and 37 per cent at 300 F. All the rupture stress *versus* *K* curves appeared to have the same general shape, with the exception of the compression curves for Plaskon 920 and Selectron 5003 laminates. The latter two curves have irregular shapes including abrupt changes in slope. There were insufficient data to draw these curves accurately.

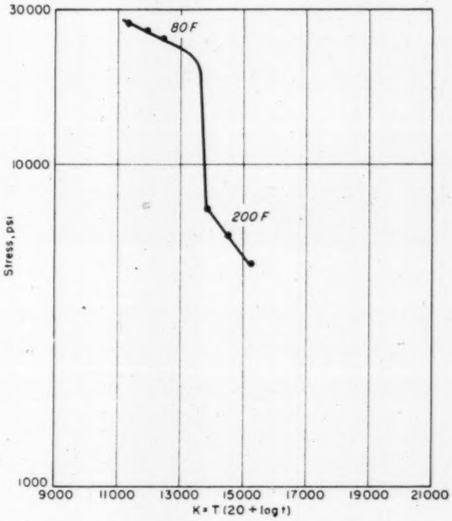

FIG. 12.—Stress to Produce Compressive Rupture *versus* *K* Selectron 5003.

Examination of the Larson-Miller rupture *K* curves for steel alloys revealed that they possessed one or more sharp breaks similar to the Plaskon 920 and Selectron 5003 compression curves. Breaks in the alloy curves were attributed to important changes in the flow and fracture process. The rupture and creep behavior of high polymers, especially laminates, are generally less predictable than those of metal because of a number of complicating factors. Barring such conditions, the breaks would probably represent abrupt changes in the relaxation mechanisms.

TABLE II.—TIME TO RUPTURE LAMINATES CALCULATED FROM *K* VALUES.

Temperature, deg Fahr	Resin	Type Stress	Time, hr	$K \times 10^{-3}$ (calculated)	Stress, psi, from Stress *versus* *K*	Stress, psi, from Extrapolating Time *versus* Stress Curve	Per Cent Difference
80......	Plaskon 920	Tension	43 800 (5 yr)	13.35	28 500	28 700	−0.7
200......	Plaskon 920	Tension	43 800 (5 yr)	16.25	26 000	26 650	−2.4
300......	Plaskon 920	Tension	3 000	17.45	24 500	23 000	+6.5
400......	Plaskon 920	Tension	43 800	21.20	...	...	...
80......	Plaskon 920	Compression	43 800	13.35	14 100	11 800	+19.5
300......	Plaskon 920	Compression	5 000	18.00	5 400	8 500	−36.5
400......	Plaskon 920	Compression	...	21.20	...	...	...
80......	Stypol 16B	Tension	43 800	13.35	24 500	22 550	+8.7
300......	Stypol 16B	Tension	43 800	18.75	21 300	21 850	−2.5
500......	Stypol 16B	Tension	43 800	22.65	...	...	...
80......	Stypol 16B	Compression	43 800	13.35	19 200	21 000	−8.6
300......	Stypol 16B	Compression	43 800	18.75	6 150	6 150	0
500......	Stypol 16B	Compression	...	23.65	...	...	...
80......	Selectron 5003	Tension	43 800	13.35	31 000	31 800	−2.6
200......	Selectron 5003	Tension	...	16.25	...	...	...
80......	Selectron 5003	Compression	...	13.35	22 000	22 600	−2.7
200......	Selectron 5003	Compression	...	16.25	...	...	...

The rupture stress *versus* *K* curves might be used for purposes other than those described. For instance, impact strengths have been determined by the Izod impact test and by dropping balls on plates. The former may be considered a flexural-impact test and the latter a compression-flexural impact test. The time of application of load may be considered to be approximately 0.03 sec. At 73 F, the *K* value would be 7900. Thus, the impact stress induced in a material due to a sudden blow might be determined by consulting the appropriate rupture stress *versus* *K* curve at a *K* value of 7900. The stress, of course, would vary with the temperature.

The effect of low as well as high temperatures on the strengths might be determined from the curves. As the temperature decreases, *K* decreases (see Eq 4). Examination of Figs. 7 through 12 shows an increasing slope with a decreasing *K*, indicating an increase in strength with a decrease in temperature. This is in accordance with the results obtained with these materials by the National Bureau of Standards and the Bureau of Ships in their laboratories.

The upper practical limit of the curve for the metals was the temperature at which surface oxidation took place. The corresponding limit for the plastics would probably be the temperature at which thermal decomposition set in.

No mention has been made regarding master creep curves, although the Larson-Miller paper indicated that the creep curves for steel were similar to the rupture curves. Preliminary calculations and plots which were drawn indicated that the creep curves of the plastics under tensile stresses were similar in shape to the rupture curves. The compressive creep data were too sketchy; consequently, no conclusions can be reached regarding them.

It is probable that the relationship would hold for any material on bonded assembly subject to failure by creep. Besides metals and plastics, elastomers and inorganic crystalline and noncrystalline materials could be included in this category.

In conclusion it may be stated that the time-temperature relation expressed by the parameter:

$$T(20 + \log t)$$

may be applied to tensile and compressive rupture data on laminates fabricated from polyester resins reinforced with glass fibers with the following results:

1. Application of this relation allows the use of short-time tests at elevated temperatures to determine long-time data at room temperature.

2. The degree of accuracy is not known because no long-time data are available as a check.

3. Long-time rupture data obtained by extrapolation of time-stress curves agree in most cases with data obtained by use of the parameter.

REFERENCES

(1) "Elevated Temperature Properties of Glass Fabric Base Plastic Laminates," *USAF Technical Report No. 6172*, Battelle Memorial Institute, May 31, 1950.

(2) J. H. Holloman and L. C. Jaffe, "Time-Temperature Relations in Tempering Steel," *Transactions*, Am. Inst. Mechanical Engrs., Iron and Steel Division, Vol. 162, pp. 223–249 (1945).

(3) F. R. Larson and James Miller, "A Time-Temperature Relationship for Rupture and Creep Stresses," *Transactions*, Am. Soc. Mechanical Engrs., July, 1952, pp. 765–775.

DISCUSSION

Messrs. J. A. Van Echo[1] **and W. F. Simmons**[1] (*presented in written form*).—The work upon which the author has based his paper was carried out at Battelle Memorial Inst. under contract with the Materials Laboratory, Wright Air Development Center. Since this has been a continuing program, we feel that we have enough information to give a short discussion of this paper.

It certainly is unfortunate that there are not more long-time creep and rupture properties available on reinforced plastics. Anyone looking for long-time data will soon become aware of the sparsity of data available. However, extrapolating short-time data to very long times can be very hazardous and should be undertaken with extreme caution. Our work for WADC was, of course, limited in its scope to the conditions of time, temperature, and stress of interest to the Air Force, and we wish to offer a few words of caution in extrapolating these data.

The author has made use of the Larson-Miller parameter method of plotting the data and has used a value of 20 for C in the equation, $C + \log t =$ a constant. A value of 20 for C has been found to be a reasonably average value for most ferritic and austenitic steels. However, C is not constant and may vary widely for different materials.

Our re-examination of the original data for these laminates strongly indicates that there are insufficient data to derive a reasonably accurate value of C. This may be the reason why the assumed value of 20 was used. Regardless of the limited data, calculations were made resulting in values of C ranging from 1 to 7. Thus, not only is there an apparent wide variation in calculated values of C, but none of these values appear to be in the vicinity of the assumed value of 20.

Reinforced plastics are extremely unstable, especially at the higher temperatures and long periods of time. The original data show the following approximate resin losses for the three polyester resin laminates after 600-hr exposure as follows:

Temperature, deg Fahr	Resin Loss, per cent	Weight Loss, per cent
500	75	25 to 30
400	50	17
300	3–6	1 to 2
200	½ to 3	½ to 1

Also, there is a wide variation in the rupture properties of reinforced plastics. As much as 100 per cent variation has been found to exist in one laminate from one lot to another. There is also, for various reasons, considerable variation in strength properties from one panel to another and even from center to edge of the same panel. The hazard of estimating 5-yr (43,800 hr) room- or elevated-temperature rupture-strength properties from a maximum 1000-hr elevated temperature test data should be appreciated. This is true regardless of whether the 5-yr estimates are calculated by means of the Larson and Miller equation or extrapolated from the existing curves. Estimates of 5-yr rupture-strength properties from 1000-hr test data would hardly be considered even for metals where little or no known physical changes occur and the materials are consistently uniform in quality.

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[1] Battelle Memorial Institute, Columbus, Ohio.

MR. H. W. KUHLMANN.[2]—Such an interpretation shows the fallacy of extrapolation of comparatively short-time high-temperature data to long periods of time at lower temperatures. The data show conclusively that the laminates suffered severe loss in weights at the higher temperatures; thus the extrapolation is being made on a laminate showing severe deterioration.

MR. E. L. HORNE.[3]—I am affiliated with the Creep Rupture and Fatigue Section of the Wright Air Development Center Materials Laboratory which has been following closely the Battelle creep work sponsored by the Plastics Section of the Organic Materials Branch of the laboratory. Because Mr. Goldfein's paper incorporates data from the above program and because comments following those of the speaker were critical of the program since long-time tests up to 5 yr were not conducted, I think it might give better perspective to this group if the original objectives of the program are reviewed. The purpose of the program was to obtain adequate elevated-temperature mechanical-property information to meet Air Force requirements on several plastic materials in their current state of development. Since the Air Force to date has no need for five-year creep-rupture data, low stress tests to obtain extremely long times to failure were not required.

Also since the plastics industry is continually improving the quality and properties of the materials through changes in formulation, fabrication, and curing techniques, expensive tests for long periods of time on a material which might be superseded before the tests are completed were not warranted.

MR. ALBERT G. H. DIETZ[4] (*by letter*).—The Larson-Miller equation is an intriguing one which appears to have a considerable body of data on metals to support it. Some such equation, by which short-time tests at elevated temperatures could be extrapolated to longer periods at normal temperatures would be highly desirable in the use of reinforced plastics, and the Larson-Miller equation may be applicable. The writer knows of no data which will either support or deny the hypothesis. The field of reinforced plastics is so new that test data, particularly those extending over long periods, are fragmentary.

The rather abrupt changes in the compressive stress-K curves for certain laminates at various temperatures may possibly result from the structure of the laminates. In compression the strength properties are to a large extent dependent upon the ability of the resin to support the reinforcing fibers against buckling under compressive stress. At elevated temperatures there may well be sufficient softening and weakening of the resin to permit early buckling of the fibers and thereby result in a lowering of the rupture stress. There may be some critical temperature region in which such weakening occurs rapidly.

MESSRS. S. S. MANSON AND W. F. BROWN, JR.[5] (*by letter*).—In attempting to apply the Larson and Miller time-temperature parameter to stress-rupture data determined for several plastic laminates, Mr. Goldfein has implied some broad generalizations regarding the use of this time-temperature relationship which are not justified by the limited data available.

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[2] Plastics and Rubber Division, Battelle Memorial Institute, Columbus, Ohio.

[3] Materials Engineer, Metals Branch, Materials Laboratory, Wright Air Development Center, Wright-Patterson Air Force Base, Ohio.

[4] Professor of Building Engineering and Construction, Massachusetts Institute of Technology, Cambridge, Mass.

[5] Lewis Flight Propulsion Laboratory, National Advisory Committee for Aeronautics, Cleveland, Ohio.

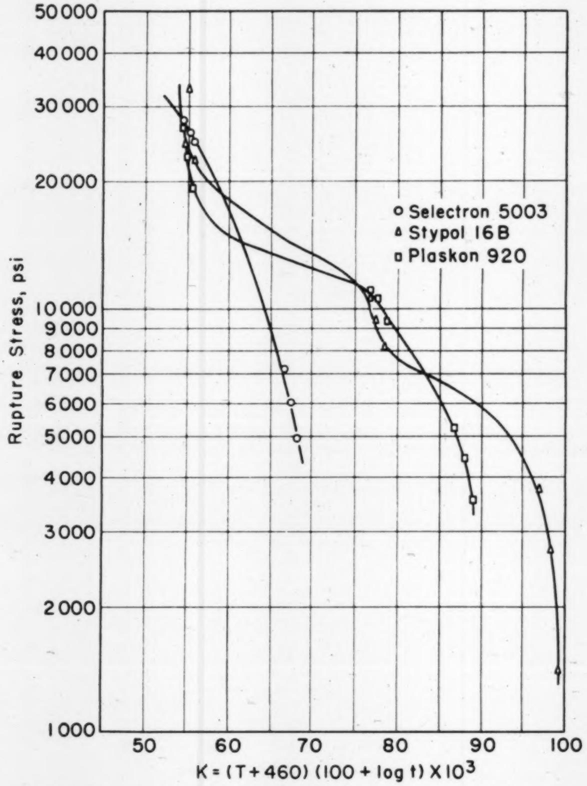

FIG. 13.—Rupture Stress for Compression Tests on Several Plastics Plotted Against the Parameter $(T + 460)(100 + \log t)$.

Apparently the author has based his arguments for the possible application of the parameter to plastics on two criteria: (1) a single curve can be drawn through the various groups of points when stress is plotted as a function of $K = T(20 + \log t)$ and (2) the extrapolated 5-yr rupture stresses obtained by the use of the K curves agree with those obtained by the linear extrapolation of the rupture-stress *versus* time plots.

Regarding the first criterion, it should be noted that in general the data points fall into isolated groups corresponding to the various temperatures investigated. In such a case, any arbitrary parameter will yield a plot through which a single curve may be drawn. For example, the compression data (Fig. 8) for Plaskon 920, Stypol 16B, and Selectron 5003 are replotted in the accompanying Fig. 13 using the rather unreasonable parameter $T(100 + \log t)$. A single curve can still be drawn through the points and on the basis of this criterion there would be little reason to select either parameter as superior. However, it is obvious that the predicted behavior of the material over the entire range of time, temperature, and stress would be entirely different, depending on the parameter selected. Only in cases where there is overlap of data (a given stress range on the *K* curve should be established by tests at several temperatures) is the criterion of all points fitting a single curve valid. The author's data do not possess such overlap.

Regarding the second criterion, the fact that the two methods of extrapolation yield the same result does not prove that either method is correct. Actually, the agreement in several cases is not as good as implied by the author. Thus, it should be noted for Stypol 16B in tension (Fig. 3) that while the two methods are less than 10 per cent different in stress at 80 F, the 5-yr rupture stress predicted by the *K* curve (Fig. 9) is greater than the 1000-hr rupture stress at this temperature as established by the data. In the case of Selectron 5003 tested in either tension or compression, the *K* curves (Figs. 11 and 12) could be drawn to yield appreciably different 5-yr results while still passing through the data equally well. Thus, the accompanying Fig. 14 shows an alternate *K* curve for Selectron 5003 tested in compression which yields a 5-yr rupture stress at 80 F 52 per cent lower than that obtained by extrapolation of isothermal data.

The most convincing way to evaluate an extrapolation method is to check it against experimental data obtained in the region of extrapolation. This cannot be done in this case, since there are no data for rupture times over 1000 hr. There is no assurance that the isothermal curves would maintain the same shape at extremely long rupture times as they exhibit in the investigated time range. In fact, the linearity assumed by the author to long rupture times seems highly unlikely in view of the data for metals which in general exhibit increasing slope of the isothermals with increasing rupture time and also in view of the fact that the high-temperature data for Plaskon

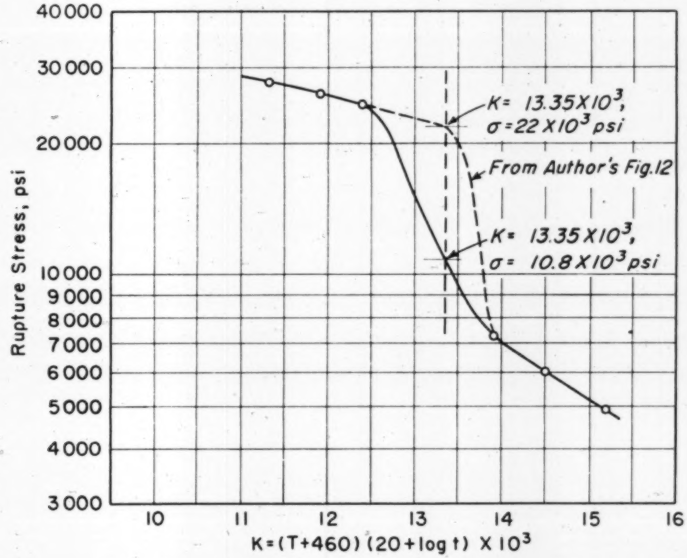

FIG. 14.—Comparison of 5-yr 80 F Rupture Stresses for Selectron 5003 Tested in Compression Obtained by Drawing Two Alternate *K* Curves Through Data in Fig. 12.

920 exhibits such curvature. In the absence of long-time data some insight into the validity of the parameter might be obtained if data with considerable stress overlap would establish a single K curve. As already pointed out, no such overlap exists in the author's data. Furthermore, it has been shown[6, 7] that the Larson and Miller parameter has serious limitations in the correlations of creep and stress-rupture data for metals.

Finally, it should be pointed out that the author's suggestions regarding the extension of application of this parameter to processes other than creep certainly cannot be based on any interpretation of the data reported in this paper.

MR. WILLIAM N. LAWRENCE[8] (*by letter*).—With the rapid growth in the field of reinforced plastics and the expected growth in the future, to apply an existing theory for metals to the field of plastics appears useful. The problem of creep-rupture in plastics is one that has barely been touched upon, and yet is very important if reinforced plastics are to be used in any permanent type of structure.

It might, however, appear that this work is premature for two reasons. First, there is very little data with which to work. Second, on the whole, the existing data does not fit into the correlations that are available. With respect to the former, only three laminates were tested in tension and compression. Unlike metals, glass reinforced plastics have different properties in tension and compression. Thus, while Larson and Miller claim that their parameter will hold for compression in metals, there is no positive reason to suppose that the data on plastics in compression will correlate in the manner as the data for tension. Perhaps if more data were avilable, it would be possible to ascertain the validity of the results.

The second criticism is that the compression data, in particular, does not form a continuous curve. The tension data might well be interpreted as a family of straight line on the stress *versus* K graph. It seemed possible that a correlation of the type proposed by Manson and Brown[7] might be applied so that the tension data, at least, would yield a continuous curve on which the points from different temperature ranges would overlap. The method of analysis proposed by Manson and Brown was used, as well as a modified form. The Manson and Brown equation was found to be unsatisfactory because at some temperatures the stress *versus* the log time relationship was linear, and at other temperatures it was nonlinear. The Manson and Brown equation cannot be used to correlate such data because of its inherent characteristics.

The equation has the form

$$(T - T_a)(\log t - \log t_a)^{\alpha} = A(\log \sigma_a - \log \sigma)^{\beta}$$

and if the stress *versus* log time relationship is linear, it cannot be correlated to a function of log stress and log time without the use of an infinite series.

It seemed possible, however, that with only a slight change in data a plot of log stress *versus* log time might also appear to be a straight line. That is the case due mainly to the fact that there is not much variation in the stress along the constant temperature lines. Even so, some data appears to be nonlinear at one temperature and linear at another. Data of this nature cannot be correlated because, if the temperature is held constant at $T =$

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[6] S. S. Manson and A. M. Haferd, "A Linear Time-Temperature Relation for Extrapolation of Creep and Stress-Rupture Data," Nat. Advisory Comm. Aeronautics TN 2890, March, 1953.

[7] S. S. Manson and W. F. Brown, Jr., "Time-Temperature-Stress Relations for the Correlation and Extrapolation of Stress-Rupture Data," *Proceedings*, Am. Soc. Testing Mats., Vol. 53, p. 693 (1953).

[8] Physicist, Engineer Research and Development Laboratories, Fort Belvoir, Va.

T_1, the slope of curve of log t *versus* log σ is

$$\frac{d\,(\log t)}{d\,(\log \sigma)} = -\frac{A}{T_1 - T_a}\left(\frac{\beta}{\alpha}\right)(\log \sigma_a - \log \sigma)^{(\beta/\alpha)-1}$$

If the ratio of β/α is unity, the curve is a straight line, irrespective of the value of T_1. If the ratio is not unity, there is curvature since both the first and second derivatives exist, irrespective again of the value of T_1. Since α and β are fixed constants, the ratio of β/α must either be unity or nonunity, and thus, linear data at one temperature cannot be correlated with nonlinear data at another temperature. It became apparent that the Manson and Brown equation was not applicable to this data.

It was felt that perhaps a modification of the Manson and Brown equation might be used to give fair results. Further attempts were made using stress *versus* log time, log stress *versus* log time, and stress *versus* temperature. However, no correlation was obtained that could be considered superior to either the work of Mr. Goldfein or a linear extrapolation by graphical means, where the data allowed it.

MR. S. GOLDFEIN (*author's closure*).—The purpose of this work was to achieve a reasonable approximation of what could be expected in the way of rupture stresses in glass-fiber reinforced plastics (GRP) over long periods of time at room temperature. By "reasonable approximation" is meant agreement within 10 per cent. "Long periods of time" are interpreted to mean periods up to 5 yr. "Room temperature" is taken to mean 80 F. By "achieving" is meant the rapid evaluation of many specimens without tying up expensive equipment for more than a few weeks. Application of the Battelle data to the formula by Larson and Miller was a first attempt in this direction.

Van Echo and Simmons have reported that values of 1 to 7 for C gave good agreement. Manson and Brown have shown in Fig. 13 that a value of 100 for C produced smooth curves. Analysis of some of these curves showed that they also gave good agreement when the temperature differential was small (100 to 200 F) and the time factor was as large as 5 yr. We found that a value of 20 for C produced good agreement in most cases. Larson and Miller showed that the scatter of points on the parameter is insensitive to changes in C. They also showed that C was relatively independent of stress. By plotting log t against the reciprocal of the absolute temperature for constant stress, straight lines were obtained. When $1/T = 0$, the value of log t equals $-C$, which is an ordinate intercept. Regardless of the stress, the value of log t at $1/T = 0$ is the same. Changing the value of C changes the value of the intercept resulting in raising or lowering the curve and the relation of K to the rupture stress. It does not change the relationship between rupture stress, time, and temperature provided the curve is fairly linear in the case in question. Most of the master curves with which we are concerned are linear in the temperature range 80 to 300 F and time range of 5 yr down to a fraction of a second.

The instability of GRP at elevated temperatures over long periods of time is well known. There is no necessity, however, for conducting tests at elevated temperatures for long periods of time to determine long-time data at room temperature. For example, the K value for 5 yr at 80 F = 13,350. At what temperature should the test be conducted if the time period is one hour?

$$13\ 350 = T\,(20 + \log 1)$$
$$T = 667.5\ R = 208\ \text{F}$$

At this temperature, in one hour, there is no effect on the laminate or plastic. Actually, the time could be shortened to 2 to 10 min if desired, and a static test could be run on standard test equipment. The theoretical basis for such static tests will be shown in a later paragraph.

It is not clear why Van Echo discusses how widely variable GRP can be fabricated. It has no significance since in all scientific investigations it is understood that the purest, most uniform materials should be used in order to obtain results which can be duplicated. He states that "as much as 100 per cent variation has been found to exist in one laminate from one lot to another." Fortunately, he did not use those specimens for the work reported in *USAF Report No. 6172* (**1**). He presented acceptance data as follows:

Plaskon 920 laminate, compressive strength, 34,900 psi
  (Maximum deviation from average ±14 per cent)
Stypol 16B laminate, flexural strength, 35,000 psi
  (Maximum deviation from average +5, −6 per cent)
Selectron 5003 laminate (no data presented)

It is of interest to note, however, that closer agreement was obtained, as is shown in Table II, with Stypol 16B laminates (5 to 6 per cent deviation in strength than with Plaskon 920B laminates (14 per cent deviation).

There is nothing mysterious about time. It is what happens during any given time period that is of any significance. For example, scientists do not hesitate to extrapolate half-life decomposition data from radioactive carbon and uranium to thousands and billions of years, respectively, because the factors which can affect the structural breakdown of these elements are known. We do know, for instance, that such factors as crystal growth, oxidation, diffusion, tempering, overaging, strain sensitivity, changes in chemical structure, etc., do affect the strength of the alloys described by Larson and Miller in the temperature ranges in question.

We appear to have a much simpler problem in dealing with GRP. The factors to be considered are oxidation, chemical and physical decomposition at elevated temperatures, and continued polymerization at room and elevated temperatures. Extensive tests by the Bureau of Standards and other agencies have indicated that one of the chief virtues of GRP is their resistance to oxidation and corrosion and their stability under normal conditions. I have already demonstrated that chemical and physical decomposition are not factors in the temperature range in question. It has been shown, however, that glass reinforced plastics do continue to polymerize and become stronger with time at both room and elevated temperatures, if they have been cured at room temperature initially. If properly catalyzed, GRP fabricated with polyester resins ordinarily achieve maximum strength if cured at 250 F for 15 min. (Mold heat-up time may add 15 to 30 min to this time depending on material and design.) Thus, GRP fabricated at room temperature should be given an after-cure to bring them up to maximum strength.

A report (**4**) on rupture and creep properties of GRP known for their stability at high temperatures added information to the subject. Plastics DC2104, CTL 91LD, and PDL-7-669 were used to fabricate the laminates. Data taken from this report and plotted (accompanying Figs. 15, 16) using the Larson-Miller parameter gave close results in most cases when it was possible to extrapolate the time-stress curves. This was not always possible since they were curved in many instances.

The master rupture curves, Figs. 15

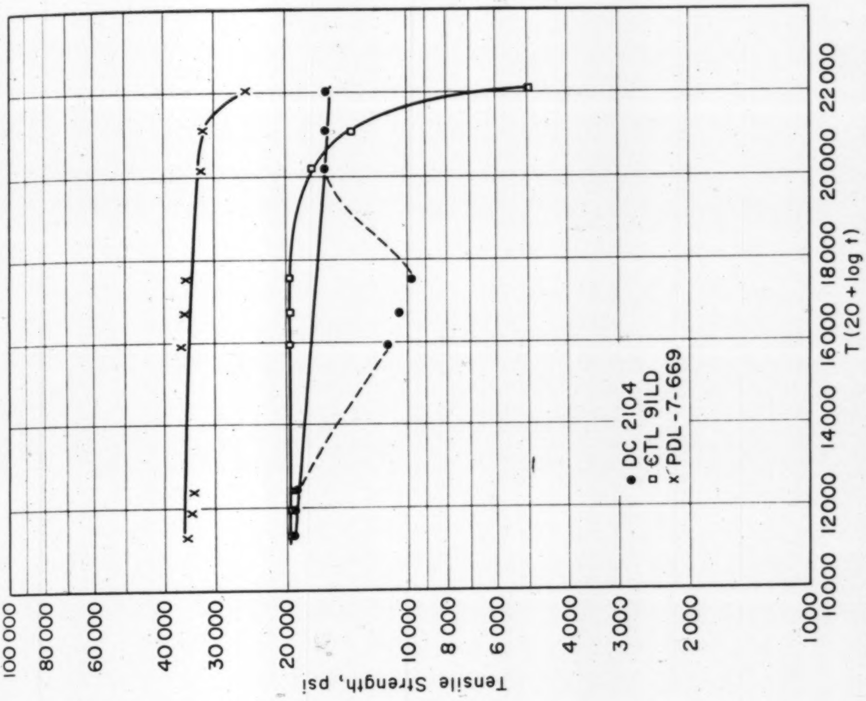

FIG. 16.—Tensile Rupture Stress *versus* T (20 + log t) for No. 181 Style Glass Cloth Laminates.

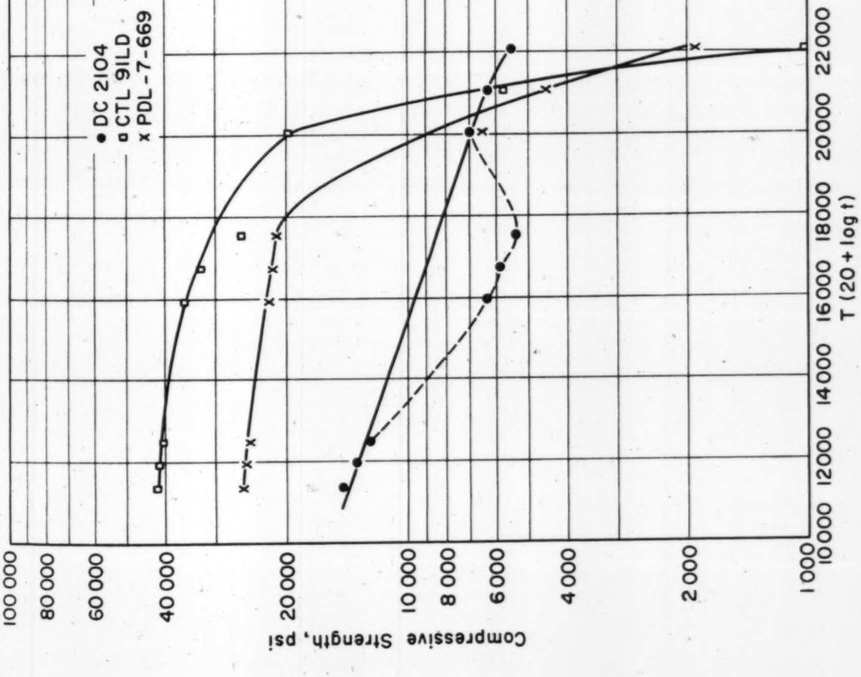

FIG. 15.—Compressive Rupture Stress *versus* T (20 + log t) for No. 181 Style Glass Cloth Laminates.

and 16, for the silicone DC-2104 laminate[9] show decreases and then increases and then decreases again in slope if the points are followed religiously. The other curves are much smoother flowing and are similar to the curves in my paper with the exception of the Plaskon and Selectron compression curves in Figs. 8 and 12. An explanation is offered for these irregularities. On p. 28 of the paper, the comment is made: "It seems that if the material (DC-2104) can withstand the applied stress for a short period of time, 0.1 hr, it becomes strengthened, perhaps by additional curing, and will sustain the applied load until the test is discontinued." On p. 29, the conclusion is made: "These three special tests seem to indicate that the DC-2104 material had not been cured sufficiently in manufacture to attain its maximum strength." Comparison of the Plaskon 920 compression curve in Fig. 8 with the DC-2104 curves in Figs. 15 and 16 carries forcibly to our attention the close resemblance between the two sets of curves. The Selectron 5003 curve also shows close resemblance to the DC-2104 curve, but it is incomplete. It appears very possible that incomplete cure, or some other defect resulting in the same condition, is responsible for the shape of the Plaskon 920 and Selectron 5003 compression curves. Both the tensile and compressive curves for DC-2104 show the same irregularities. The tension curve of the Plaskon 920, on the contrary, was smooth while the compression curve was irregular. The records indicate, however, that the compression and tension specimens were taken from different laminates. It is possible, therefore, that the tension specimens were cured satisfactorily, while the compression specimens were not. The Selectron specimens were taken from the same laminate, but the tension curve is so short it is impossible to discern the true trend.

TABLE III.—RESULTS OF CORRELATION OF OVERLAP DATA.

Laminate	Type of Stress	Temperature, deg Fahr	Time, hr	*K*	Stress Level from Time Stress Curve, psi	Source of Data	Stress from Master Rupture Curve, psi	Deviations, per cent
Stypol 16B	Tension	300 80	100 600	16 720 12 280	24 000	Fig. 3	24 000 24 800	0 +3
Stypol 16B	Compression	300 500	1000 0.0024 (8 sec)	17 450 16 500	8 000	Fig. 4	8 000 9 900	0 +24
Plaskon 920	Tension	80 200	23 0.00003 (0.1 sec)	11 520 9 750	29 500	Fig. 1	29 500 29 800	0 +1

The report by Manson and Brown[7] on correlation and extrapolation of stress-rupture data on steel alloys was critical of the Larson and Miller parameter, and suggested instead another method. This method comprised an extremely complicated form of curve fitting, the theory upon which it was based being quite nebulous. An attempt to use the method failed both because of lack of sufficient data and general unsuitability. Mr. W. Lawrence has made a study of the work and has discussed it above. While it is

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[9] J. A. Van Echo, *et al*, "High Temperature Creep-Rupture Properties of Glass-Fabric-Plastic Laminates," Wright Air Development Center Technical Report 53-491, Dec. 1953.

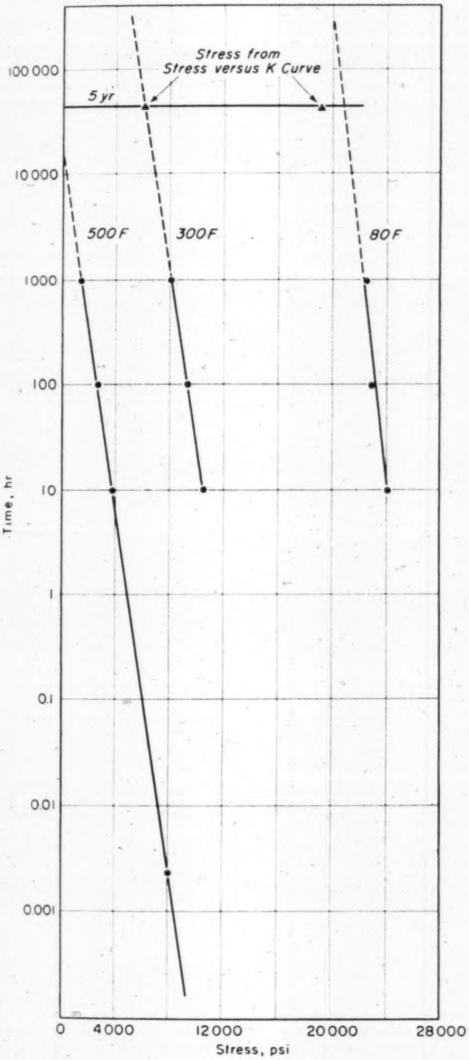

FIG. 17.—Stress to Produce Compression Rupture in Stypol 16B Laminates.

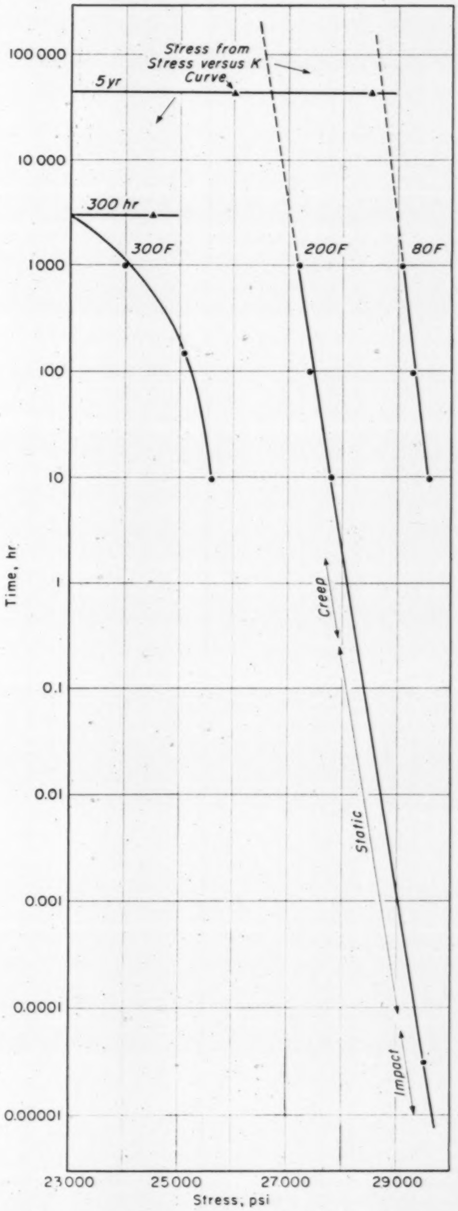

FIG. 18.—Stress to Produce Tension Rupture in Plaskon 920 Laminates.

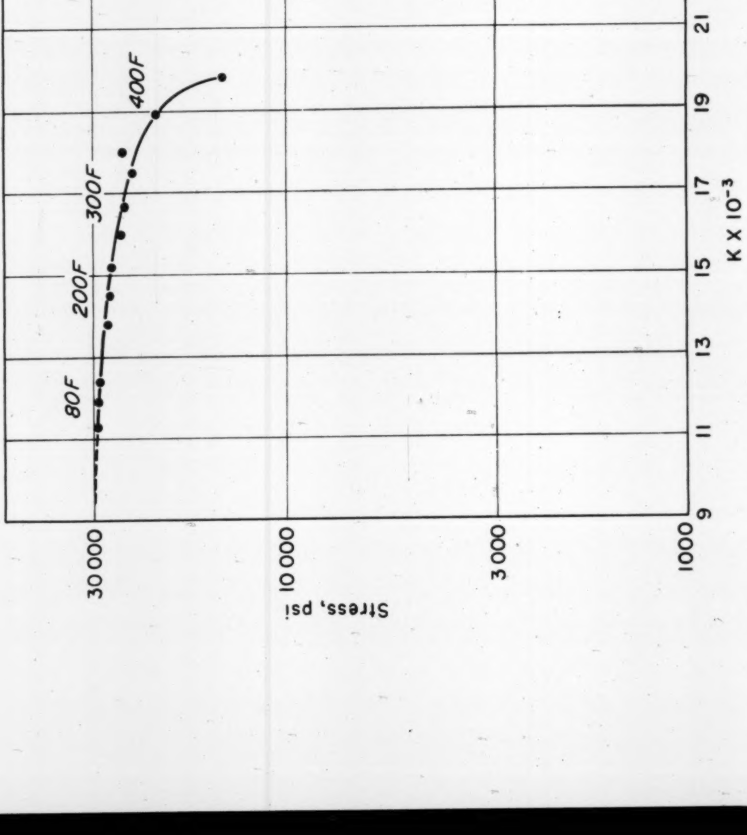

FIG. 19.—Stress to Produce Tension Rupture *versus* *K* (Plaskon 920).

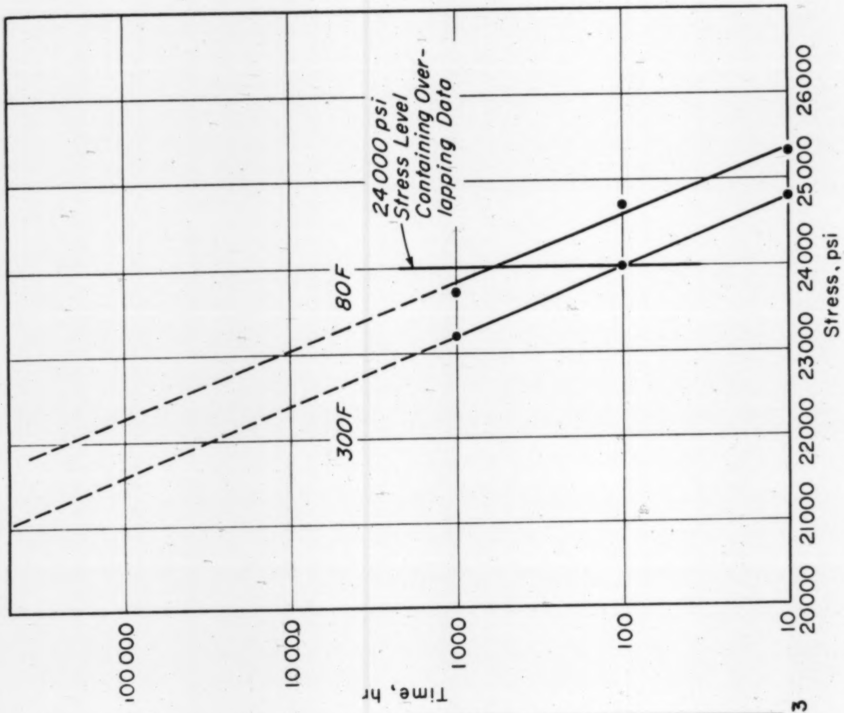

FIG. 20.—Stress to Produce Tension Rupture in Stypol 16B Laminates.

beyond the scope of this discussion to discuss the relative merits of the Larson-Miller parameter and the Manson-Brown method in great detail, it was found that wherever the former parameter departed from the correct results by an appreciable amount, it was invariably due to a change in physical structure occasioned by the heat treatment. The parameter should not be required to form one continuous curve for widely different materials.

In reply to Manson and Brown, it is true that any arbitrary parameter will yield a plot through which a single curve may be drawn. Emphasis on the smooth curves was made to distinguish them from the connected series of lines which represented the master rupture curves of the metals. Usually, the former type of curve has more validity and is more natural than the latter type.

No overlap of data has been presented in the paper. An examination of curves revealed that most of them were too far away from each other to permit such data to be obtained. It was possible, however, to obtain data from some of them. The results are shown in Table III.

The tension data from Stypol 16B in Fig. 3 and the accompanying Fig. 20 was the only scource of direct data available without resorting to extrapolation. The results were excellent, since the agreement was within 3 per cent. The charge might be made, however, that the master curve in Fig. 9 is almost level in the 80 to 300 F range or that any *K* value between 11,000 and 17,000 would give the same result. This should not be blamed on the curve since it only reflects the properties of the material. Actually, such a low slope is required by the properties of the material. The data on compression for Stypol 16B is even more interesting. In order to obtain overlapping data, the 500 F curve in Fig. 4 was extrapolated backwards in time until it crossed the 8000 psi stress level (accompanying Fig. 17). This occurred in the neighborhood of 0.0024 hr, or 8 sec. The agreement was very good (+24 per cent) considering that it was extrapolated 4 decades and that the resin had evidently undergone some decomposition in 1000 hr at 300 F. If this extrapolation was made forward it would represent a period of 2000 yr. In addition, the master curve had a steep slope (Fig. 8). The third correlation was the tension data of Plaskon 920. Here, again, the time-stress curves were extrapolated backwards (accompanying Fig. 18). A common stress level of 29,500 psi was used for the 80 and 200 F curves. The latter was extrapolated to a time of 0.00003 hr or 0.1 sec. This represented an extrapolation forward of one more decade than the Stypol B compression data. The *K* value for the 200 F, 0.1 sec extrapolation was 9750 which was off the master rupture curve (accompanying Fig. 19). The curve in this region, however, is almost a straight line and was extrapolated backwards to obtain the required rupture stress. The agreement was +1 per cent.

The time element involved in the example given (Stypol 16B) was 8 sec. This is a little fast, but might be considered a "static" test. In the case of Plaskon 920, the time period was 0.1 sec. This may be considered impact, for all intents and purposes. Thus the parameter may be applied to other "processes" than creep. There is a question, however, of whether there is any fundamental difference between the three processes (creep, static, impact). Maxwell and Harrington[10] found in their work with methyl methacrylate on the effect of velocity on tension impact properties, that there was no difference between static and impact phenomena. They showed in this work that high and low rates of loading are related and that the impact test is really only a special case of the slow rate or "static test." Their work investigated the fundamental processes related to impact and static phenomena, and included experimental data which confirmed their theories. If there is no fundamental difference between static and impact processes, there can surely be none between creep and static processes. The master rupture curves thus allow the presentation of the complete rupture characteristics of a laminate on a single curve. Static tests, which are the most accurate and economical to conduct, may be used to prepare the master rupture curves.

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[10] B. Maxwell and J. P. Harrington, "The Effect of Velocity on the Tensile Impact Properties of Methyl Methacrylate," *Technical Report 19A*, Plastics Laboratory, Princeton University, to Signal Corps on Contract DA-36-039-SC-133.

Finally, as I concluded in the paper, "the degree of accuracy is not known because no long-time data are available as a check." The Bureau of Ships has let a contract to the Forest Products Laboratory to determine the "Effects of Long-Term Loading on Glass Reinforced Plastics" (Project NS-034-045, Subtask 30). The objective of this study is to "obtain creep and stress-rupture data on typical reinforced plastics for loading periods up to about 5 yr." We have arranged to obtain samples of the laminates with which they are working in order to set up master-rupture curves according to the Larson-Miller parameter. The results from this work will be checked with the results obtained from the long term tests. This work should be completed some time in 1958.

A NEW TRIAXIAL STRESS TESTING MACHINE FOR DETERMINING PLASTIC STRESS-STRAIN RELATIONS*

BY H. A. B. WISEMAN[1] AND JOSEPH MARIN[1]

SYNOPSIS

This paper describes a new machine for testing metals under triaxial stresses. The stresses applied consist of two equal compressive principal stresses with the third principal stress either tension or compression. These triaxial stresses are produced by subjecting a cylindrical specimen to radial hydraulic pressure and axial tension or compression. By means of these triaxial stress tests, mechanical properties of materials under various states of triaxial stresses can be obtained and triaxial plastic stress-strain relations can be determined. These tests also serve to check further the validity of plasticity theories used to predict plastic stress-strain relations under combined stresses.

This paper also describes a preliminary investigation dealing with plastic stress-strain relations for an aluminum alloy 14S-T6 subjected to the triaxial state of stress described. Each test was conducted with a constant ratio of the principal stresses, this ratio being varied from test to test to discover its effect on the plastic stress-strain properties. The test results show that the simple flow theory of plasticity is in approximate agreement with the test results.

Most available information on plastic stress-strain relations for materials subjected to combined states of stress have been determined for biaxial tension-tension or tension-compression stresses. Very little information is available on the influence of triaxial states of stress on the plastic stress-strain relations. Most of the information that is available is of a qualitative nature.

It is important to obtain information on triaxial plastic stress-strain relations in order to determine both the influence of such stresses on the mechanical properties and to evaluate the validity of theories defining the plastic stress-strain relations in metals. It appears highly desirable to determine the accuracy of a theory of plasticity based on the general three-dimensional state of stress rather than the restricted two-dimensional states of stress used in the past. For this reason the investigation on triaxial stresses described in this paper was initiated.

PREVIOUS INVESTIGATIONS

Several investigations have been made in which triaxial stresses were produced by applying either an internal or external pressure to a thick-walled cylinder with closed ends. Bridgman (1)[2] investigated the plastic triaxial stress-strain relations for several steels using thick-walled cylindrical specimens with closed ends subjected to external pressures. He found poor agreement between the simple flow theory of plasticity and test results for large strains.

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* Presented at the Fifty-seventh Annual Meeting of the Society, June 13–18, 1954.

[1] Department of Engineering Mechanics, The Pennsylvania State University, State College, Pa.

[2] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 1381.

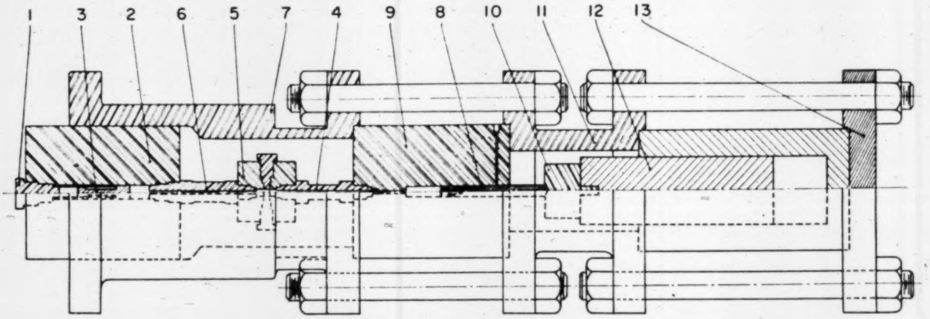


FIG. 1.—Triaxial Stress Machine.

1—plug. *2*—testing vessel. *3*—specimen. *4*—pipe. *5*—6-way connector. *6*—pipe. *7*—casting. *8*—piston. *9*—pressure vessel. *10*—piston seat. *11*—casting. *12*—ram. *13*—end plate.

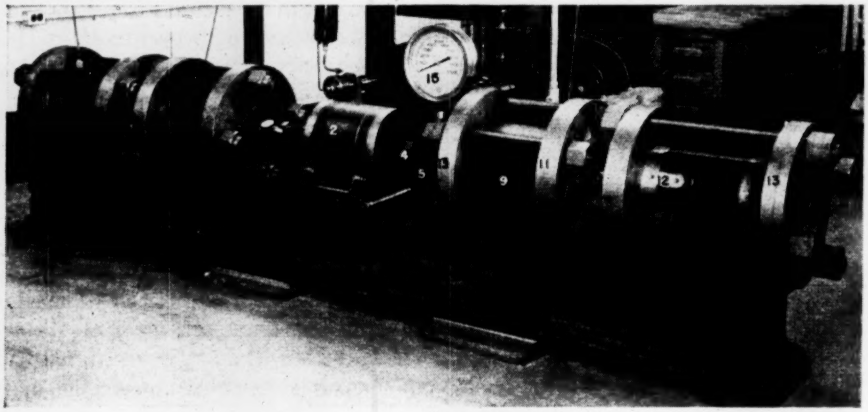


FIG. 2.—Triaxial Stress Machine.

MacGregor, Coffin, and Fisher (2) subjected to internal pressure thick-walled, closed-end tubular specimens made of a 17S-O aluminum alloy. With this type of specimen plastic stress-strain relations for triaxial stresses were obtained. Discrepancies between theories and test results were also noted in this study.

Although the foregoing test results, as well as others that have been reported using thick-walled cylindrical specimens, give useful information, they cannot give accurate plastic stress-strain data for triaxial state of stress. For accurate information on triaxial plastic stress-strain relations, it is necessary to use a specimen in which the state of stress is essentially uniform throughout the specimen. In a thick-walled cylinder subjected to internal or external pressures, this uniform state of stress cannot be obtained.

In order to investigate the influence on mechanical properties of triaxial stresses with a uniform state of stress, Bridgman (1) used solid cylindrical specimens subjected to axial tension or compression and radial compressive pressure. The plastic stress-strain relations obtained in these investigations were restricted to axial strains; strains in other directions were not measured in these tests, so that the validity of plasticity theories could not be checked. Bridgman did, however, obtain considerable information on mechanical properties of metals subjected to triaxial stresses.

TRIAXIAL STRESS INVESTIGATION ON ALUMINUM ALLOY 14S-T6

In the following, a new type of triaxial stress machine is described in which a cylindrical specimen is subjected to radial compressive pressures and axial tension or compression. In this manner, a triaxial state of stress could be obtained and the mechanical properties for such a state of stress investigated. For the first time (to the authors' knowledge) plastic stress-strain relations were obtained utilizing measured values of both axial and tangential strains.

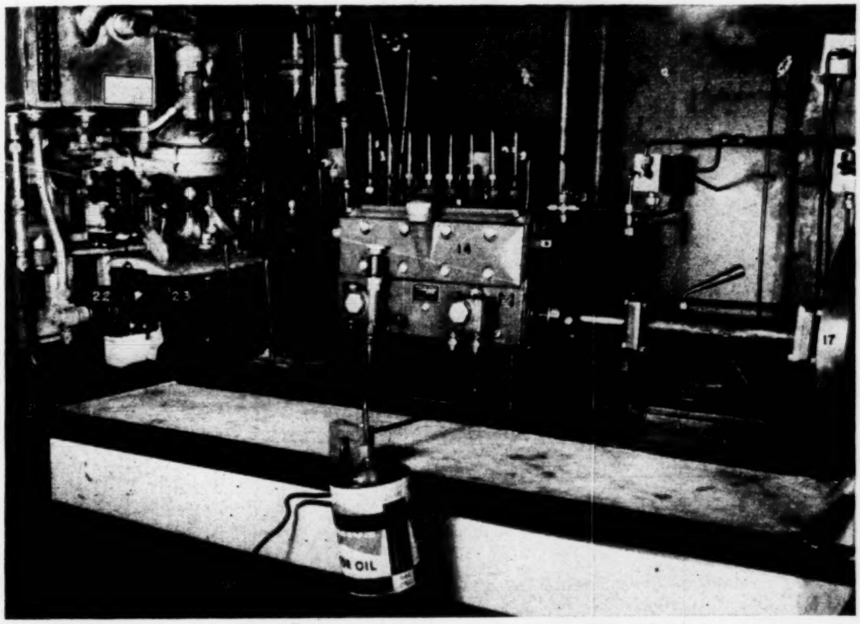


FIG. 3.—Bosch Pump and Auxiliary Pumping Unit.

PART A—DESCRIPTION OF TRIAXIAL STRESS MACHINE

For applying radial compression and axial tension to a cylindrical specimen, a testing machine was developed consisting essentially of two high-pressure units. One of these pressure units is used to apply radial pressures, as well as an axial tensile load of a specific amount, whereas the second pressure unit is employed to control the magnitude of the axial tension or compression. Figures 1 and 2 show, respectively, a schematic drawing and a photograph of one of the pressure units of the triaxial machine. The numbers designating the component parts of the machine are the same for both figures.

The specimen, *3*, is placed in the testing vessel, *2*, in such a manner that the right-hand side of the specimen is fixed, whereas the left-hand side is free to move in its axial direction. A Bosch pump, *14*, shown in Fig. 3 pumps oil against a ram, *12*, in Figs. 1 and 2. The ram transmits the force through a hardened steel piston seat, *10*, to a piston, *8*. Since the piston area is much less than that of the ram, the pressure on the specimen is much greater than that delivered by the Bosch pump. The ratio of the area of the ram to that of the piston gives a measure of increase in pressure. The movement of the piston, *8*, increases the pressure of the fluid in the vessel, *9*. This pressure vessel is connected by thick-walled tubing, *4* and *6*, to a testing vessel, *2*. The oil pressure applies radial compressive forces to the cylindrical specimen. In addition, this pressure, acting on the collar attached to the end of the specimen, produces an axial tensile force L in the specimen (Fig. 5). In this way two equal compressive principal stresses and a tensile principal stress can be applied to a test specimen. For tests in which it is necessary to vary the ratio of the axial tensile stress to the radial compressive stresses, a second pressure unit is used to apply axial compression.

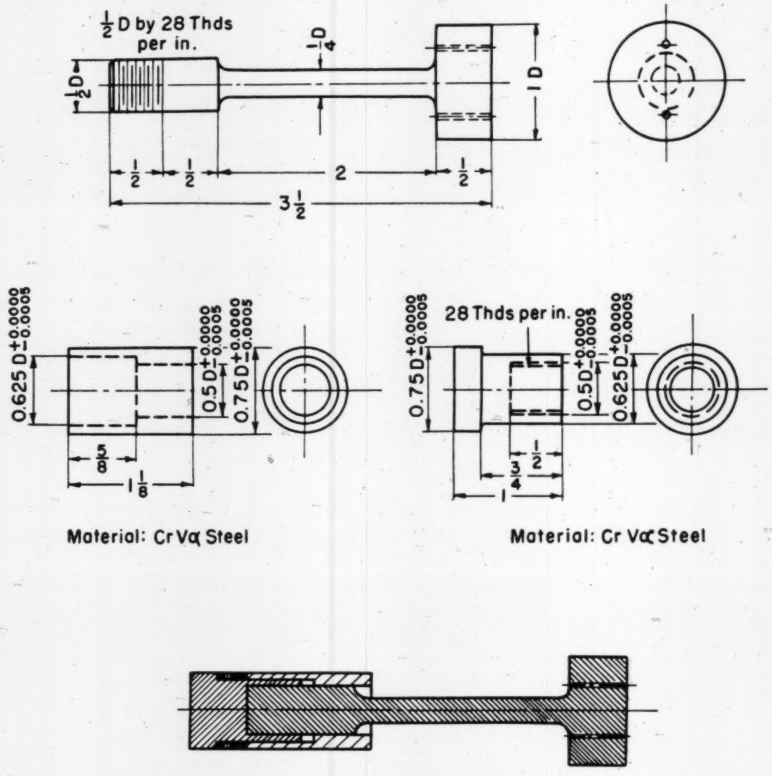
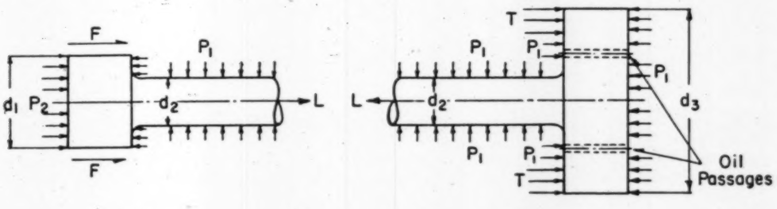

½ D by 28 Thds per in.
D/4
½D
1 D
½
½
2
½
3½
0.625 D +0.0000 −0.0005
0.5 D +0.0000 −0.0005
0.75 D +0.0000 −0.0005
5/8
1⅛
Material: Cr Va Steel
28 Thds per in.
0.75 D +0.0000 −0.0005
0.5 D +0.0000 −0.0005
0.625 D +0.0000 −0.0005
½
¾
1
Material: Cr Va Steel

FIG. 4.—Specimen and Assembly for Triaxial Tests.

Between the tubes, *4* and *6*, there is a

6-way connector, *5*, by which various electrical leads are brought out of the high-pressure testing vessel, *2*. This is necessary since various electrical strain and pressure measurements must be made within the vessel during the testing of the specimen.

Figure 2 also shows a Bourdon tube type pressure gage, *15*. This gage has a capacity of 100,000 psi and is used for pressure measurements with tests in which the maximum pressure does not exceed 100,000 psi.



(a) (b)

FIG. 5.—Specimen Free Body.

SPECIMEN

Figure 4 shows details of the specimen and auxiliary parts. It can be seen that one of the heads of the specimen is made larger than the other. This is done in order to fix the large head in the testing vessel and allow axial movement of the small head. The fixing of the large head in the testing vessel is accomplished by placing the smaller head of the specimen in a sleeve, with the large one butted up against the end of the sleeve.

The sleeve has mounted on it two SR-4 strain gages. This sleeve was calibrated using a series of compressive loads applied by a universal testing machine. Compressive loads applied on the sleeve through the large head of the specimen can be determined from the SR-4 gage readings during a test.

The smaller head of the specimen is placed as shown in Fig. 4. Since this head is free to move in the sleeve, and since it also must not allow any passage of oil between it and the sleeve wall, it must be sealed in some manner. For this purpose Koroseal rings are mounted as shown in Fig. 4. However, since this specimen head must be able to move, the Koroseal rings may produce considerable friction between the specimen head and the sleeve wall. The effective total force on the test section of the specimen will therefore depend upon both the pressure and friction between the specimen head and sleeve wall.

The method employed to evaluate the frictional force can be explained by the use of the free body diagrams shown in Figs. 5(*a*) and (*b*).

In Fig. 5(*b*), T is the thrust load acting on both the fixed end of the specimen and the end of the sleeve. As previously explained, this thrust load is measured by the use of SR-4 gages. To determine the force L in the specimen and the friction force F in terms of the known diameters d_1, d_2, and d_3 and pressures p_1 and p_2, two equations of equilibrium for the forces acting in Figs. 5(*a*) and (*b*) can be written:

$$p_2\frac{\pi d_1^2}{4} + F + L - \pi\frac{(d_1^2 - d_2^2)}{4}p_1 = 0 \ldots.(1)$$

$$L + \left[\frac{\pi d_3^2}{4} - \pi\frac{d_1^2 - d_2^2}{4}\right]p_1 - T = 0 \ldots..(2)$$

It can be seen by Eqs 1 and 2 that there are only two unknown quantities, L and F, and since there are two equations available these forces can be evaluated. It is actually not necessary to compute the value of F, the frictional force, since only the force L is required for calculating the axial stress in the specimen. However, values of F were obtained in order to have some idea of their magnitudes.

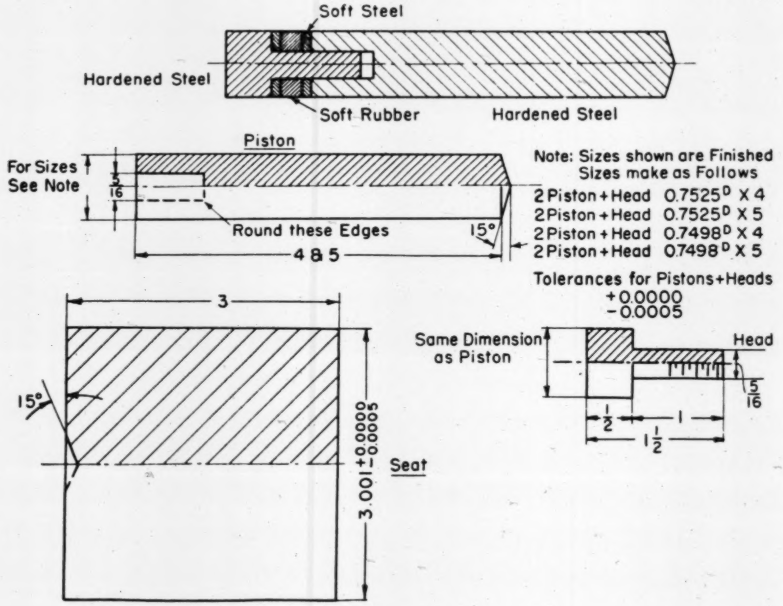

Soft Steel
Hardened Steel
Soft Rubber
Hardened Steel
Piston
For Sizes See Note
5/16
Round these Edges
15°
4 & 5
Note: Sizes shown are Finished Sizes make as Follows
2 Piston + Head 0.7525D X 4
2 Piston + Head 0.7525D X 5
2 Piston + Head 0.7498D X 4
2 Piston + Head 0.7498D X 5
Tolerances for Pistons + Heads
+0.0000
-0.0005
3
15°
3.001 +0.0000 -0.0005
Seat
Same Dimension as Piston
Head
5/16
1/2
1
1 1/2

FIG. 6.—Piston and Assembly.

Application of Load:

To develop the large pressures required, a stepped piston, *8* and *12*, is used as previously explained and as shown in Fig. 1. This piston is in two parts, one being $5\frac{1}{2}$ in. in diameter and the other about 0.75 in. in diameter. By means of the stepped piston, a pressure applied to the large piston is magnified by the ratio of the area of the large piston to that of the small one or by about 54 times.

The large piston, *12*, has an 8-in. stroke and is part of a standard commercial hydraulic jack. The small piston, *8*, operates in a special cylinder, *9*, having an external diameter of 10 in. and an internal diameter of about $\frac{3}{4}$ in. To provide an effective seal under extremely high pressures, an arrangement using a Bridgman type of packing was employed (Fig. 6). In order for the small piston to withstand the high stresses developed, it was made of a tool steel, heat treated to its maximum hardness, and not tempered.

The most important feature of the step piston arrangement is the alignment of the two pistons with their respective cylinders. Since the small piston must be made extremely hard, the steel in this condition is not capable of withstanding any appreciable amount of tensile strain. Therefore, no bending must occur in the small piston, and the alignment of the small and the large pistons must be exact. This requires very close tolerances during the machining processes and during assembly. In order to help this alignment, the pressure vessel (*9* of Figs. 1 and 2) and the hydraulic jack containing the large piston, *12*, are mounted between castings, *7* and *11*, and an end plate, *13*, that were specially machined to the same outside diameter. The whole unit was then placed horizontally on the ways of a lathe bed (Fig. 2), which was used since the ways on such a base are probably as parallel as possible. Figure 2 does not show the casting (*7* of Fig. 1) so that the testing vessel, *2*, and the 6-way connector, *5*, can be shown more clearly.

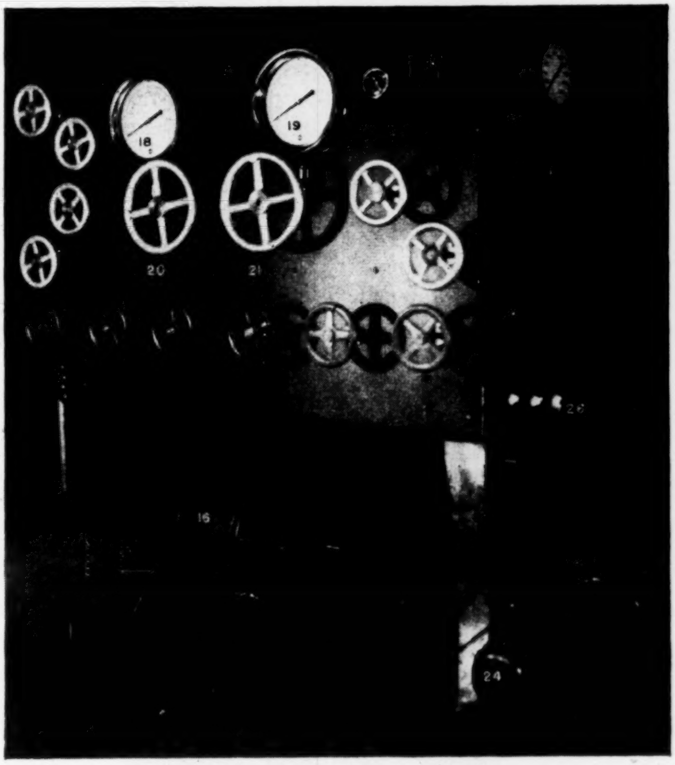


FIG. 7.—Pressure Control Panel.

16—d-c motor. *18, 19*—gages. *20, 21*—control valves. *24*—d-c motor generator set. *25*—gage. *26*—rheostat.

In order to test specimens subjected to various ratios of the axial to the radial stresses, a second pressure intensifier was built as described above (Fig. 1). The second pressure intensifier is also arranged on the same lathe bed of Fig. 2.

The maximum hydrostatic pressure that can be developed with equipment similar to that described is about 500,000 psi. The development of higher hydrostatic pressures has been limited by the fact that for higher pressures all liquids are in a solid state and thus incapable of transmitting true hydrostatic pressures. For these extreme pressures the fluid used is a mixture of equal parts of isooctane and isopentane.

To design pressure vessels to withstand pressures of the order of 500,000 psi, it was necessary to obtain steels of the highest quality. The required mechanical properties of the materials to be employed could best be obtained by the use of alloy tool steels. In order to insure maximum soundness throughout the steel, all the tool steels used were forgings, and upset forgings were used where larger pieces of steel were required, thus further insuring soundness throughout the metal.

To develop and employ pressures of the order of magnitudes stated above, it is necessary to use thick-walled vessels and containers. Experience has shown that cylinders having a ratio of external to internal diameter of about ten is satisfactory. Sometimes it is necessary to use prestressed cylinders, usually produced by shrinking one cylinder onto the other.

The testing vessel built for this machine is 12 in. long with an outside diameter of 10 in. and an internal diameter of 1 in. The length of the test section is about 5 in. The testing vessels were heat treated and tempered to a hardness of about Rockwell C46 on their outside surface. For the steel used, this allows maximum toughness to be developed.

LOW-PRESSURE SYSTEM

To develop the pressures required to drive the large piston (*12* of Fig. 1), an American Bosch fuel injection pump was modified and used (*14* of Fig. 3). This pump has eight plungers with diameters of 0.3 cm each. To control the speed of operation of this pump, it was coupled to a d-c motor (*18* of Fig. 7) through a pulley system (*17* of Fig. 3). Figure 3 is a photograph showing the apparatus on the back of the operation panel seen in Fig. 7. The power for the d-c motor is supplied by a special motor generator set. The pressure from the pump is measured on the Bourdon type pressure gages, *18* and *19*, and is controlled by valves, *20* and *21*, that meter the flow of fluid past a needle valve. By opening or closing the needle valve the flow from the pump can be controlled and in this manner the pressure can be varied. The original pressure developed by this pump was about 1500 psi. By the arrangement used here, the pressures developed are up to about 10,000 psi.

An auxiliary pumping unit (*22* of Fig. 3) capable of developing about 1000 psi is used to supply the Bosch pump with fluid and also to prefill the system. This auxiliary pumping unit is used since its output is about $3\frac{1}{2}$ gal per min at 1000 psi, compared to that of the Bosch pump of about 0.15 gal per min. The auxiliary pump, driven by a 28-v d-c motor (*23* of Fig. 3), was originally employed to drive a gun turret in an airplane. The power is supplied to this motor by a special motor generator set (*24* of Fig. 7). The pressure of the auxiliary pump is measured by a Bourdon pressure gage, *25*, and is controlled by a rheostat, *26*, which in turn controls the speed of its driving motor (*23* of Fig. 3).

Measurement of Pressure:

A primary gage capable of measuring the high pressures directly has not as yet been developed. An example of a primary gage is a free floating piston upon which weights of known magnitude can be placed. Knowing the magnitudes of the weights and the diameter of the piston, the pressure can be calculated. It is called free floating, because in order to measure the pressure accurately there must be no friction between the piston and its cylinder wall. There is, however, a limit to the capacity of this type of gage since, under higher pressures, leakage past the piston walls becomes excessive and does not permit the building up of pressures above some limit. The maximum capacity free floating piston dead weight testing machine available today is 100,000 psi.

A secondary gage is one that is calibrated against a primary gage and then used with this calibration on the required equipment. A Bourdon tube type of pressure gage is an example of a secondary gage. For tests in which pressures do not exceed 100,000 psi, a Bourdon tube type pressure gage is available as shown as *15* in Fig. 2.

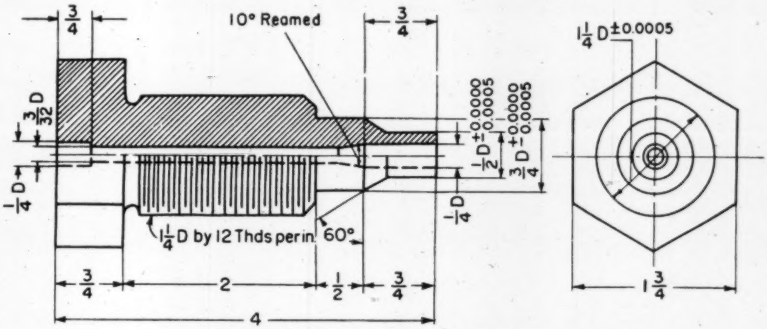


FIG. 8.—Electrode Plug.

The type of secondary gage used for pressures exceeding 100,000 psi is a coil of specially wound manganin wire immersed in the fluid of the high-pressure system. It has been found that the electrical resistance of manganin wire varies linearily with pressure. To measure pressure by use of manganin wire, a length of this wire is wound noninductively into a coil and submerged in the fluid to be pressurized. This coil is calibrated up to the capacity of the tester with a free floating piston dead weight tester. The pressure resistance curve obtained is then extrapolated to the required range of pressures, assuming that the extrapolated relationship continues to remain linear. Bridgman (**3**) has checked the accuracy of this method for pressures up to 185,000 psi and has found the assumed linear relationship to hold within a few per cent.

The manganin coils used in the apparatus described herein were calibrated on a free floating piston dead weight testing machine of 50,000 psi capacity, and checked with a Bourdon tube type pressure gage of 100,000 psi capacity.

Figure 8 is a drawing of the type of electrode plugs employed in the present work for the purpose of bringing electrical leads from within the test chamber.

The electrode must be insulated from the walls of the container and yet must be able to withstand the pressures applied to it. High pressures subject the insulating materials to severe stresses and often cause the extrusion of these materials and the electrodes. At times when the electrode pin itself fails suddenly, it is ejected at extremely high velocities. Special shielding is therefore employed to prevent injury to personnel in the event of such an occurrence.

Measurement of Strains:

Under certain types of constant stress ratio conditions where the pressure is applied to the test specimen (*3* of Fig. 1) only by one pressure intensifier, there is fluid only on one side of the movable head of the test specimen. It is then possible to pass a straight length of drill rod through the plug (*1* of Fig. 1) and butt it against the movable head of the test specimen. The other end of the drill rod is placed in contact with the plunger of a specially mounted dial indicator. The readable accuracy of this dial indicator is 0.0001 in. By this method the movement of the specimen head can be obtained and the over-all deformation of the test specimen determined. The influences of end effects of the specimen on the strains can be determined by calibration.

Part B—Constant Stress Ratio Tests

Material Tested

The material tested was an aluminum alloy designated as 14S-T6. The material was supplied in the form of extruded solid rod about 10 ft long and 1 in. in diameter. The normal composition, in addition to aluminum and normal impurities, consists of 4.4 per cent copper, 0.6 per cent silicon, 0.8 per cent manganese, and 0.4 per cent magnesium. The design and dimensions of the machined specimen have already been described.

Plastic stress-strain relations for various constant values of the triaxial stress ratios were obtained using the triaxial stress machine described.

Conventional Stress-Strain Results

The average conventional stress-strain curves for various principal stress ratios and for axial and radial stress components are shown in Figs. 9 and 10. The values of the nominal radial stresses used are the same as the applied pressure. The values of the nominal axial stresses were determined with the aid of Eqs 1 and 2. Since it was found that the friction force was negligible, values of the thrust load T were not obtained. For the loading conditions used in these tests, $p_2 = 0$ and Eqs 1 and 2 reduce to:

$$L = \pi \frac{(d_1^2 - d_2^2)}{4} p_1 \ldots\ldots\ldots\ldots (3)$$

where L is the axial load in the specimen. Therefore, the nominal axial stress is:

$$\sigma_1' = \frac{L}{\frac{\pi d_2^2}{4}} = \left(\frac{d_1^2 - d_2^2}{d_2^2}\right) p_1 \ldots\ldots (4)$$

The nominal strain corresponding to σ_1' is:

$$e_1 = \frac{\Delta l}{l_0} \ldots\ldots\ldots\ldots\ldots (5)$$

where Δl is the plastic change in length and l_0 is the original gage length.

The radial strains are equal to the tangential strains and have a value of:

$$e_2 = e_3 = \frac{-\Delta d}{d_0} \ldots\ldots\ldots\ldots (6)$$

where Δd is the plastic change in diameter and d_0 is the original diameter.

Plastic Stress-Strain Results:

To determine the plastic stress-strain relations, the changes in the dimensions of the specimens must be considered and the actual stresses and strains calculated. The value of the actual axial stress in terms of the nominal stress can be shown to be (4):

$$\sigma_1 = \sigma_1'(1 + e_1) \ldots\ldots\ldots\ldots (7)$$

The radial stresses will remain, as before, equal to the applied pressure.

The true strains will also be different due to the changes in dimensions. There are several possible ways of defining the true plastic strains. True strains cor-

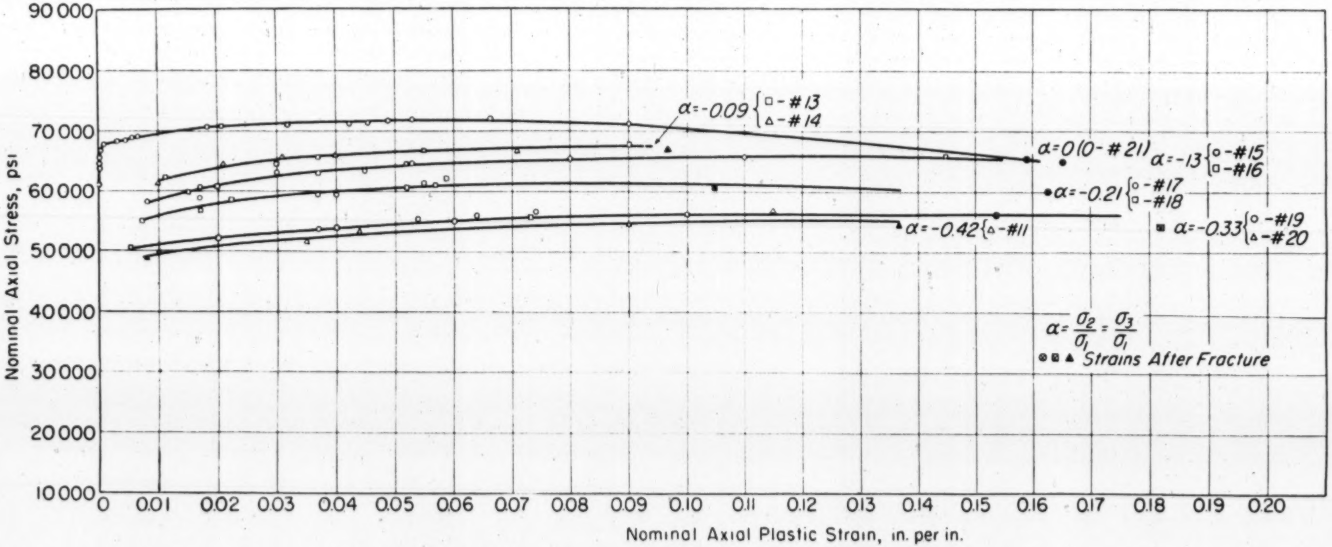


FIG. 9.—Nominal Stress-Strain Relations for Constant Stress Ratio Tests.

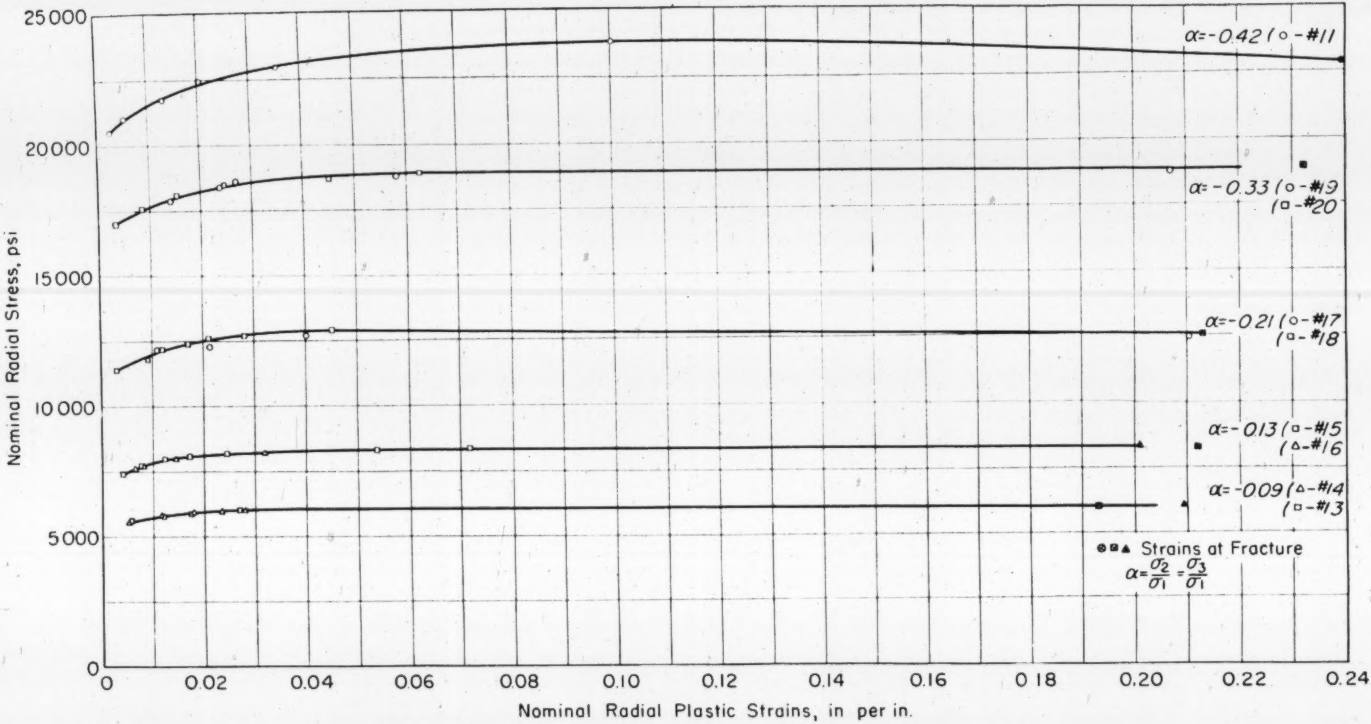


FIG. 10.—Nominal Stress-Strain Relations for Constant Stress Ratio Tests.

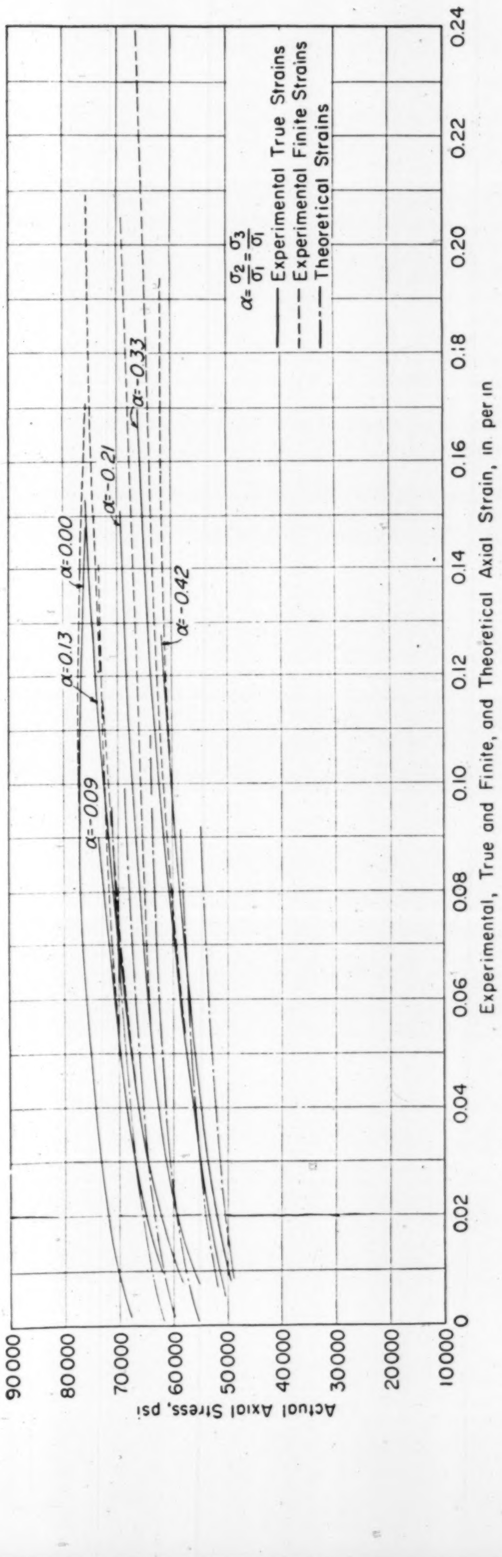


FIG. 11.—Comparison of Plastic Stress-Strain Relations for Constant Stress Ratios.

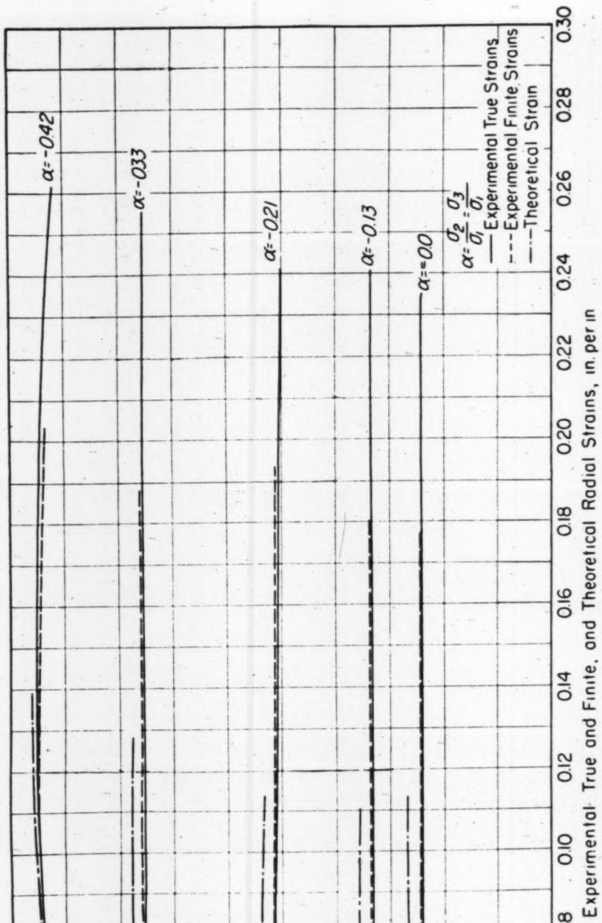


FIG. 12.—Comparison of Plastic Stress-Strain Relations for Constant Stress Ratios.

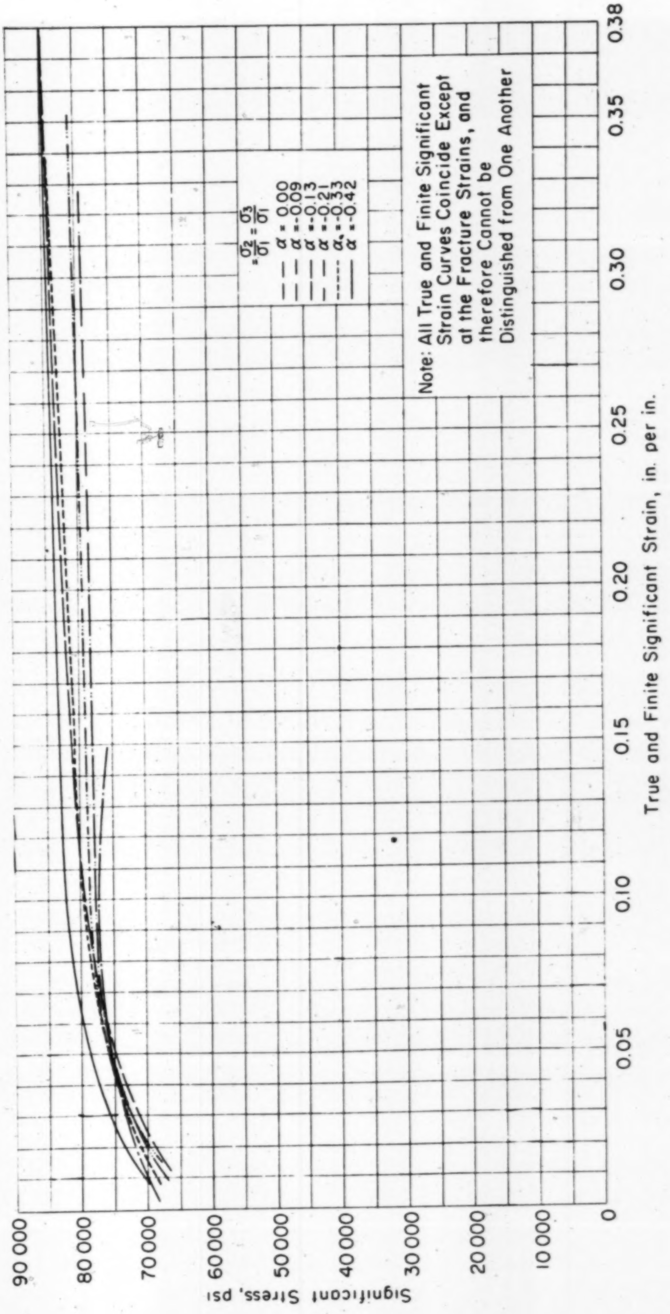


FIG. 13.—Significant Stress-Strain Relations.

responding to nominal strains e_1, e_2, and e_3 have been shown to be (4):

$$\epsilon_1 = \ln(1 + e_1) \ldots\ldots\ldots\ldots (8)$$

and:

$$\epsilon_2 = \epsilon_3 = \ln(1 + e_2) \ldots\ldots\ldots\ldots (9)$$

However, it has recently been indicated by Hu (5) that these definitions of the true strains may not be sufficiently accurate for certain stress conditions. For this reason Hu proposed the use of finite strains based on the geometry of the deformation. For the conditions of the present tests, these finite strain components in terms of the nominal strains can be shown to be (5):

$$\epsilon_1 = e_1 + (e_2)^2 \ldots\ldots\ldots\ldots (10)$$

and:

$$\epsilon_2' = \epsilon_3' = e_2 + \frac{(e_1)^2}{2} + \frac{(e_3)^2}{2} \ldots\ldots (11)$$

The actual stresses and both the true and finite strains used in plotting Figs. 11 and 12 are those defined by Eqs 7 and 11.

Analysis and Discussion:

A comparison of the flow theory of plasticity and experimental results was made by plotting the significant stress-strain relations as shown in Fig. 13.

The flow theory of plasticity is described in detail in reference (6). It is a theory which expresses the plastic stress-strain relations for combined stresses in terms of the plastic stress-strain relation in simple tension. In order to compare these theoretical and experimental values, it is convenient to describe combined states of stress and strain by so-called significant stress and strain. The significant stress and strain can be shown to be, respectively (4):

$$\bar{\sigma} = \frac{1}{\sqrt{2}} [(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2]^{\frac{1}{2}} \ldots (12)$$

and:

$$\bar{\epsilon} = [\tfrac{2}{3}(\epsilon_1^2 + \epsilon_2^2 + \epsilon_3^2)]^{\frac{1}{2}} \ldots\ldots\ldots (13)$$

For the loading conditions of the tests conducted, $\sigma_2 = \sigma_3$, $\epsilon_2 = \epsilon_3$, and Eqs 12 and 13 reduce to:

$$\bar{\sigma} = (\sigma_1 - \sigma_2) \ldots\ldots\ldots\ldots (14)$$

and:

$$\bar{\epsilon} = [\tfrac{2}{3}(\epsilon_1^2 + 2\epsilon_2^2)]^{\frac{1}{2}} \ldots\ldots\ldots (15)$$

Both the true and the finite strains of Eqs 8 to 11 were used in plotting Fig. 13 to indicate the differences in the significant stress-strain relations arising by using both true and finite strains.

The calculations of the significant strains using both the true and the finite experimental values showed that they are almost identical and exhibit differences only for the extreme strain values obtained from each test. Figure 13 can show only these extreme value differences since the remainder of the curves coincide. By the flow theory all the relations in Fig. 13 should coincide with the simple tension plastic stress-strain relation. An examination of Fig. 13 shows that the agreement is within about 5 per cent, using the stress as a basis.

In Figs. 11 and 12 the plastic stress-strain relations are compared with the values predicted by the flow theory. These results show that the flow theory gives a fair approximation to the test results.

CONCLUSIONS

For the Alcoa 14S-T6 tested and for triaxial stresses represented by combined radial pressure and axial tension, it can be concluded that the plastic stress-strain relations for combined stresses and constant stress ratios are approximated by the flow theory. The theoretical values are within about 10 per cent of the experimental curves.

Acknowledgment:

The research reported in this paper was conducted under the sponsorship and with the financial assistance of the Office of Ordnance Research, U. S. Army. The help of L. W. Hu and Edward Paxson in conducting this program is also acknowledged. The study also represents, in part, a Ph.D. thesis conducted by H. A. B. Wiseman under the supervision of Joseph Marin.

REFERENCES

(1) P. W. Bridgman, "Studies in Large Plastic Flow and Fracture," Metallurgy and Metallurgical Engineering Series, McGraw-Hill Book Co., Inc., New York, N. Y. (1952).

(2) C. W. MacGregor, L. F. Coffin, Jr., and J. C. Fisher, "The Plastic Flow of Thick-Walled Tubes with Large Strains," *Journal of Applied Physics*, Vol. 19, No. 3, pp. 291–297 (1948).

(3) P. W. Bridgman, "Measurements of Hydrostatic Pressure to 30,000 kg per sq cm," *Proceedings*, Am. Acad. Arts and Sciences, Vol. 74, No. 1 (1940).

(4) J. Marin, B. H. Ulrich, and W. P. Hughes, "Plastic Stress-Strain Relations for 75S-T6 Aluminum Alloy Subjected to Biaxial Tensile Stresses," *TN 2425*, Nat. Advisory Comm. Aeronautics (1951).

(5) L. W. Hu and J. Marin, "Finite Deformation of Spherical Shells Under Radial Pressure," presented at Fourth Symposium on Plasticity, Brown University, September, 1953.

(6) A. Nadai, "Theory of Flow and Fracture of Solids," McGraw-Hill Book Co., Inc., New York, N. Y. (1950).

DISCUSSION

MR. WILLIAM PRAGER[1] (*presented in written form*).—In view of the authors' use of the term "flow theory" for what is usually called a "deformation theory," it is perhaps appropriate to define once more these terms which are due to A. A. Ilyushin.[2] A deformation (or finite) theory stipulates a relation between stress and plastic strain which is independent of the history of loading or straining. A flow (or incremental) theory, on the other hand, stipulates a relation between small increments of stress and plastic strain; in the most general case, the coefficients in this relation depend on the history of loading or straining. As is well known, the predictions of the two types of theory are in agreement for constant stress ratio tests, so that the results of such tests cannot be considered as deciding in favor of one of these theories.

There is abundant experimental evidence described in the literature that the results of constant stress ratio tests can be plotted so that the curves corresponding to different values of the stress ratios practically coincide. The authors' results add to this evidence. In this writer's opinion, far too much effort has been devoted to the search for measures of effective stress and strain, such as the authors' $\bar{\sigma}$ and $\bar{\epsilon}$, which would improve the already good agreement, and the much more urgent (and difficult) expermental exploration of stress-strain relations under more general conditions of testing has been comparatively neglected.

Experimental evidence in favor of either the flow or the deformation theory can be obtained only from a test during which the stress ratios vary significantly.[3] It is to be hoped that the authors will soon avail themselves of their new equipment to embark on a program of such tests.

MR. H. A. B. WISEMAN (*author*).—We have, since the time of this paper, conducted some tests on the variable stress ratio tests, and we hope to publish the results in the near future.[4]

As I mentioned, we can control the stresses in the triaxial directions rather well, and the reason for slowness in the results is that the extremely high pressures make it a little dangerous, and so it takes time to do this sort of work.

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[1] Brown University, Providence, R. I.

[2] A. A. Ilyushin, "Relation Between the Theory of Saint Venant-Levy-Mises and the Theory of Small Elastic-Plastic Deformations," *Prikladnaia Matematika i Mekhanika*, Vol. 9, p. 207 (1945).

[3] See D. C. Drucker and F. D. Stockton, "Instrumentation and Fundamental Experiments in Plasticity," *Proceedings*, Soc. Experimental Stress Analysis, Vol. 10, No. 2, pp. 127–142 (1953).

[4] J. Martin, L. W. Hu, H. A. B. Wiseman, and E. Paxton, "Research and Development on Plastic Flow of Metals," Army Contract No. DA-36-061-ORD-368, Depts. of Engineering Mechanics and Engineering Research, The Pennsylvania State University, State College, Pa., July 16, 1954.

SUMMARY OF PROCEEDINGS OF THE SYMPOSIUM ON ODOR

The Symposium on Odor was held at the Tenth and Fifteenth Sessions of the Fifty-seventh Annual Meeting of the Society in Chicago, Ill., on June 15, 1954. The object of the papers was to bring a status report of knowledge in the field of odor and its applications. The papers define terms, cover aspects of measurement, and deal with control. The Symposium was under the sponsorship of Committee D-22 on Methods of Atmospheric Sampling and Analysis.

The following papers were presented:

Introduction—Amos Turk
Odor: A Proposal for Some Basic Definitions—Edward Sagarin
Catalytic Method of Measuring Hydrocarbon Concentrations in Industrial Exhaust Fumes—R. J. Ruff
The Design, Construction, and Use of an Odor Test Room—Nicholas Deininger and Russell W. McKinley
Organoleptic Appraisal of Three-Component Mixtures—A. Haldane Gee
Odor Pollution from the Official's Viewpoint—Charles W. Gruber
Odor Control Methods: A Critical Review—Amos Turk

These papers, with discussions, were issued as *ASTM Technical Publication No. 164* entitled "Symposium on Odor."

SUMMARY OF PROCEEDINGS OF THE SYMPOSIUM ON COAL SAMPLING

The Symposium on Coal Sampling, sponsored by Committee D-5 on Coal and Coke, was held at the Second and Fifth Sessions of the Fifty-seventh Annual Meeting of the Society in Chicago, Ill., on June 14, 1954. Theories of sampling, the results of extensive practical tests, the variances of reduction and analysis, and new techniques of mathematical statistics were taken up in the papers.

The papers presented were:

Introduction—Arno C. Fieldner and W. W. Anderson
The Development of the Theoretical Basis of Coal Sampling—W. M. Bertholf
Some Recent British Work on Coal Sampling—R. C. Tomlinson
Tests on the Binomial Sampling Theory—Jan Visman
A Test on a Slotted Revolving Cylinder Coal Sampler—A. O. Blatter
Tests of Accuracy of a Mechanical Coal Sampler—R. L. Coryell, F. J. Schwerd, and E. J. Parente
Tests of the Geary-Jennings Sampler at Cabin Creek—W. M. Bertholf and W. L. Webb
The Variances of Reduction and Analysis—W. W. Anderson and M. L. Sutherland
Multilot Sampling—The Accuracies in Sampling of Large Coal Shipments by Application of the Variance Concept—T. A. Miskimen and R. S. Thurston

The papers and discussions were issued as *ASTM Special Technical Publication No. 162* entitled "Symposium on Coal Sampling."

SUMMARY OF PROCEEDINGS OF THE SYMPOSIUM ON TEMPERATURE STABILITY OF ELECTRICAL INSULATING MATERIALS

The papers and discussions in the Symposium on Temperature Stability of Electrical Insulating Materials, with the exception of "Electrical Properties of Thermosetting Plastics at Elevated Temperatures," by R. R. Winans and W. Hand, were presented at the Third and Sixth Sessions of the Fifty-seventh Annual Meeting of the Society held in Chicago, Ill., on June 14, 1954. The paper by Winans and Hand was added later. The Symposium is an important part of the effort to develop generally accepted standards for determining the thermal stability of insulating materials. It was sponsored by Committee D-9 on Electrical Insulating Materials.

The following papers were presented:

Introduction—K. N. Mathes
Measurement of Dielectric Properties at Temperatures Up to 500 C—A. H. Scott, P. Ehrlich, and J. F. Richardson
Dielectric Measurements on Plastics at High Temperatures—Thomas Hazen
Electrical Resistivity of Bonded Micaceous Materials at Elevated Temperatures—K. Wechsler
Test Methods for Studying Thermal Stability and Heat Aging of Insulating Varnishes—A. H. Haroldson
Thermal Stability of Insulating Fabrics—R. C. Bartlett
Electrical Properties of Thermosetting Plastics at Elevated Temperatures—R. R. Winans and W. Hand
Thermal Stability of Polyvinyl Chloride Insulating Compounds—R. C. Bartlett
The Deflected Beam-Film Rupture Test Applied to Sheet Insulation—H. I. Morgan and K. N. Mathes
Heat Aging Characteristics of Insulating Varnishes—H. I. Morgan and K. N. Mathes
A Method for Evaluation of the Thermal Aging Stability of Flexible Sheet Insulation—R. M. Plettner and C. G. Currin
Effect of Elevated Temperature on Silicone Varnished Glass Fabric for Electrical Insulation—O. E. Anderson

These papers were issued as *ASTM Special Technical Publication No. 161* entitled "Symposium on Temperature Stability of Electrical Insulating Materials."

SUMMARY OF PROCEEDINGS OF THE SYMPOSIUM ON DIESEL FUELS

The papers in the Symposium on Diesel Fuels were presented at a meeting of Committee D-2 on Petroleum Products and Lubricants, held in Philadelphia, Pa., February 17, 1954. The Symposium was sponsored by Technical Committee F, on Diesel Fuels, of Committee D-2. Papers covered the diesel fuel supply and demand outlook, the various problems associated with the procurement and usage of diesel fuels, as well as a review of the diesel fuel specification requirements which have been investigated by Technical Committee F.

The Symposium included the following papers:

Introduction—W. K. Simpson
The Availability and Demand Outlook, Distribution, and Principal Properties of Domestic Diesel Fuels—C. M. Larson
Diesel Fuel Specifications Requirements—C. C. Ward
The Increasing Use of Furnace Oils for Diesel Fuel—Harold V. Messick
Distribution and Storage Problems with Diesel Fuels—C. C. Moore and W. P. Lakin
Survey of Diesel Fuel Oils Available at Roadside Filling Stations—William A. Howe
Technical Problems Associated with Diesel Fuels in Contractors' Equipment—J. W. Vollentine
Technical Problems Associated with Diesel Fuels in Interstate Coach Operation—W. A. Duvall
Technical Problems Associated with Diesel Fuels in Railroad Operations—R. W. Seniff
Diesel Fuels in Marine Operations—C. E. Habermann

These papers were issued as *ASTM Special Technical Publication No. 167* entitled "Symposium on Diesel Fuels."

SUMMARY OF PROCEEDINGS OF WASHINGTON NATIONAL MEETING

During the 1954 Committee Week of the Society held in Washington, D. C., the following two Symposiums were presented.

SYMPOSIUM ON DESIGN OF EXPERIMENTS

The papers in the Symposium on Design of Experiments were given in the evening session on February 2, 1954. Mr. William R. Pabst, Quality Control Division, Bureau of Ordnance, U. S. Dept. of the Navy, acted as chairman. The Symposium was sponsored by Committee E-11 on Quality Control of Materials.

The papers in the Symposium were:

The Purpose of Experimental Design—W. G. Cochran
An Engineering Application of Experimental Design—Bessie B. Day and F. R. Del Priori
Design of Experiments and Physical Sciences—W. J. Youden

These papers were not published.

SYMPOSIUM ON COLOR OF TRANSPARENT AND TRANSLUCENT PRODUCTS

Sponsored by Committee E-12 on Appearance, the Symposium on Color of Transparent and Translucent Products was held in two sessions, morning and afternoon, on February 3, 1954. Dean Farnsworth, LCDR, MSC, USNR, Head, Human Engineering Branch, U. S. Naval Medical Research Lab., presided over the sessions. Mr. Deane B. Judd, Physicists, National Bureau of Standards, gave an excellent summary of the papers and was the discussion leader at the close of the afternoon session.

The following papers were presented:

Introduction—George W. Ingle
The Determination of the Color of Petroleum Products—H. M. Hancock and J. J. Watt
A Color Space for Color Grading Purposes—George W. Ingle
Color Methods in the Brewing Industry—Irwin Stone
Color Measurement and Control in the Sugar Industry—R. A. McGinnis
Color Grading Agricultural Products—Wilbur Gould, Rees B. Davis, and James O. Mavis
Colors of Transparent Liquids for Surface Coatings—Francis Scofield
Color in Dairy Products—Mark Keeney
Summary—Deane B. Judd

These papers with discussions were published in ASTM BULLETIN, Nos. 201 and 202, October and December, 1954. The papers were also published as a combined reprint.

1954 PAPERS

LIST OF SPECIAL TECHNICAL PUBLICATIONS

The publications listed below have been printed during the year 1954 and issued as separate publications not included in either Proceedings or ASTM BULLETIN. For a list of earlier Special Technical Publications, see the original listings in Proceedings, Volume 48, page 1352, and the supplementary listings in Volume 49, page 1240, Volume 50, page 1490, Volume 51, page 1322, Volume 52, page 1309, and Volume 53, page 1197. A complete list of Special Technical Publications covering all publications, up to and including 1950, is included in the 50 Year Index to ASTM Publications.

Special Technical Publication Number	Title
160	Report on Elevated Temperature Properties on Selected Superstrength Alloys (1954)
161	Symposium on Temperature Stability of Electrical Insulating Materials (1954)
162	Symposium on Coal Sampling (1955)
163	Symposium on Permeability of Soils (1955)
164	Symposium on Odor (1954)
165	Symposium on Effect of Cyclic Heating and Stressing on Metals at Elevated Temperatures (1954)
166	Symposium on Methods of Testing Building Construction (1955)
167	Symposium on Diesel Fuels (1954)
168	Viscosity Index Tables (1955)

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A Study of Some Operations Involved in Cement Analysis. Published in ASTM BULLETIN, No. 197, Apr., 43 (TP71).

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Surface Waves at Ultrasonic Frequencies. Published in ASTM Bulletin, No. 198, May, 81 (TP127).

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Davis, Rees B.
See Gould, Wilbur A., Davis, Rees B., and Mavis, James O.

Day, Besse B., and Del Priori, F. R.
An Engineering Application of Experimental Design—Summary of Proceedings of Symposium on Design of Experiments, 1387.

Decker, George E.
Note on the Adjustment of Mooney Viscometer Die Closure. Published in ASTM BULLETIN, No. 195, Jan., 51 (TP13).

Decker, George E., and Stiehler, Robert D.
Temperature Measurements in the Mooney Viscometer. Published in ASTM BULLETIN, No. 195, Jan., 45 (TP7).

Deininger, Nicholas, and McKinley, Russell W.
The Design, Construction, and Use of an Odor Test Room—Summary of Proceedings of *STP 164*, 1383.

Deitz, Victor R.
Discussion. Published in ASTM BULLETIN, No. 201, Oct., 48 (TP201); No. 202, Dec., 71 (TP257).

Del Priori, F. R.
See Day, Besse B., and Del Priori, F. R.

DeMoney, F. W., and Lazan, B. J.
Dynamic Creep and Rupture Properties of an Aluminum Alloy Under Axial Static and Fatigue Stress, 769. Disc., 783.

Diaz, R. B., Paitchel, H., and Woodhead, J. A.
Need for a Standardized Procedure for Measuring Reflectance of Detergency Fabrics. Published in ASTM BULLETIN, No. 202, Dec., 56 (TP242).

Dickson, J. B., and Davieau, L. A.
Impact Tester for Textiles. Published in ASTM BULLETIN, No. 198, May, 85 (TP131).

Dietz, A. G. H.
Discussion, 1329, 1353.

Dickinson, C. Dale
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Dimoff, T.
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Dodge, Harold F.
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Dolan, T. J.
See Corten, H. T., Dimoff, T., and Dolan, T. J.
See Corten, H. T., Sinclair, G. M., and Dolan, T. J.
Discussion, 713, 734, 783, 819.

Donahue, R. W.
Correlation of Induction Tests with Motor Fuel Stability. Published in ASTM BULLETIN, No. 200, Sept., 61 (TP187).

Dorn, John E., and Shepard, Lawrence A.
What We Need to Know About Creep—Summary of Proceedings of *STP 165*, 700.

Dougherty, Marie
See Adam, L. H., and Dougherty, Marie.

Dowdell, Ralph L., and Mackay, William B. F.
Tension Specimens Made by Photoengraving Technique. Published in ASTM BULLETIN, No. 201, Oct., 65 (TP227).

Duvall, W. A.
Technical Problems Associated with Diesel Fuels in Interstate Coach Operation—Summary of Proceedings of *STP 167*, 1386.

E

Eaton, Ian D.
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Ehrlich, Paul
See Scott, A. H., Ehrlich, Paul, and Richardson, J. F.

Eiselstein, H. L., and Skinner, E. N.
The Effect of Composition on the Scaling of Fe-Cr-Ni Alloys Subjected to Cyclic Temperature Conditions—Summary of Proceedings of *STP 165*, 700.

Eney, W. J.
See Roesli, A., Loewer, A. C., and Eney, W. J.

Enomoto, N.
On Fatigue Tests Under Progressive Stress, a Theory of Fatigue of Metals and a Quick Method for Determining the Fatigue Limit. Scheduled for publication in 1955 ASTM *Proceedings*.

Ericksen, W. S.

Analysis of Stresses Induced by a Sandwich Proof Tester. Published in ASTM BULLETIN, No. 199, July, 80 (TP158).

F

Field, Robert F.

Errors Occurring in the Measurement of Dielectric Constant, 456.

Errors Occurring in the Measurement of Dielectric Constant (Abstract). Published in ASTM BULLETIN, No. 201, Oct., 30.

Fieldner, Arno C. and Anderson, W. W.

Introduction to Symposium on Coal Sampling—Summary of Proceedings of *STP 162*, 1384.

Findley, William N.

Effect of Crystallinity and Crazing, Aging, and Residual Stress on Creep of Monochlorotrifluoroethylene, Canvas Laminate, and Polyvinyl Chloride, Respectively, 1307.

Experiments in Fatigue Under Ranges of Stress in Torsion and Axial Load from Tension to Extreme Compression, 836. Disc., 849.

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Fitzgerald, W.

Discussion. Published in ASTM BULLETIN, No. 200, Sept., 55 (TP181).

Fontana, M. G.

See Beck, F. H., Greene, N. D., Jr., and Fontana, M. G.

Foreman, R. W.

Discussion. Published in ASTM BULLETIN, No. 200, Sept., 55 (TP181)

Frazier, R. H.

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Freeman, J. W.

See Rush, A. I., and Freeman, J. W.

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Frey, D. N.

Introduction to Symposium on Effect of Cyclic Heating and Stressing on Metals at Elevated Temperatures—Summary of Proceedings of *STP 165*, 700.

Summary to Symposium on Effect of Cyclic Heating and Stressing on Metals at Elevated Temperatures—Summary of Proceedings of *STP 165*, 700.

Fricke, W. G., Jr.

See Hunter, M. S., and Fricke, W. G., Jr.

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Gee, A. Haldane

Organoleptic Appraisal of Three-Component Mixtures—Summary of Proceedings of *STP 164*, 1383.

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Gohn, G. R., Guerard, J. P., and Herbert, G. J.

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Goldie, C. H., Wright, K. A., Anson, J. H., Cloud, R. W., and Trump, J. G.

Radiographic Properties of X-Rays in the Two- to Six-Million-Volt Range. Published in ASTM BULLETIN, No. 201, Oct., 49 (TP211).

Gordon, S. A.

Discussion, 926.

Gould, Wilbur A.

Discussion. Published in ASTM BULLETIN, No. 202, Dec., 71 (TP257).

Gould, Wilbur A., Davis, Rees B., and Mavis, James O.

Color Grading Agricultural Products—Symposium on Color of Transparent and Translucent Products. Published in ASTM BULLETIN, No. 202, Dec., 61 (TP247); see also Summary of Proceedings, 1387.

Green, A. W. F.

Specifications from the Consumer Viewpoint. Published in ASTM BULLETIN, No. 203, Jan., 1955, 43 (TP3).

Green, A. W. F., Lampson, K., and Tsareff, T.

Thermal Shock Testing Under Stress of Certain High-Temperature Alloys. Scheduled for publication in 1955 ASTM *Proceedings*.

Greene, N. D., Jr.

See Beck, F. H., Greene, N. D., Jr., and Fontana, M. G.

Greenfeld, Sidney H.

Discussion. Published in ASTM BULLETIN, No. 199, July, 61 (TP139).

Griffin, Donald F.

Study and Development of Methods for Determining In-Place Densities of Cohesionless Soils, 1270.

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Odor Pollution from an Official's Viewpoint—Summary of Proceedings of *STP 164*, 1383.

Guarnieri, G. J.
The Creep-Rupture Properties of Aircraft Sheet Alloys Subjected to Intermittent Load and Temperature—Summary of Proceedings of *STP 165*, 700.

Guerard, J. P.
See Gohn, G. R., Guerard, J. P., and Herbert, G. J.

H

Habermann, C. E.
Diesel Fuels in Marine Operations—Summary of Proceedings of *STP 167*, 1386.

Hackney, Ethel J.
See Bean, Leonard, and Hackney, Ethel J.

Hafemeister, Robert N.
The Ultrasonic Testing of Forging Ingots. Published in ASTM BULLETIN, No. 197, Apr., 52 (TP80).

Hamer, J. P., Tutwiler, T. S., and Weisel, C. A.
Lubricating Oil Requirements of the Modern Automotive Engine—Symposium on Engine Lubrication. Published in ASTM BULLETIN, No. 198, May, 70 (TP116). Disc., 77 (TP123).

Hammond, Harry K., III
See Newman, Sanford B., Hammond, Harry K., III, and Riddell, Helen F.

Hancock, H. M., and Watt, J. J.
The Determination of the Color of Petroleum Products—Symposium on Color of Transparent and Translucent Products. Published in ASTM BULLETIN, No. 201, Oct., 31 (TP193); see also Summary of Proceedings, 1387.

Hand, W.
See Winans, R. R., and Hand, W.

Haroldson, A. H.
Test Methods for Studying Thermal Stability and Heat Aging of Electrical Insulating Varnishes—Summary of Proceedings of *STP 161*, 1385.

Hartbower, Carl E.
Poisson Effect in the Charpy Test, 929. Disc., 938.

Hazen, Thomas
Dielectric Measurements on Plastics at High Temperatures—Summary of Proceedings of *STP 161*, 1385.

Heger, J. J., Hodge, J. M., and Marshall, P. W.
Effect of Microstructure on the Elevated-Temperature Strength of Alloy Steel, 1003.

Heinen, C. M.
Discussion. Published in ASTM BULLETIN, No. 198, May, 63 (TP109).

Herbert, G. J.
See Gohn, G. R., Guerard, J. P., and Herbert, G. J.

Herron, Lewis F.
Discussion. Published in ASTM BULLETIN, No. 203, Jan., 1955, 72 (TP32).

Heyer, Otto C.
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See Heger, J. J., Hodge, J. M., and Marshall, P. W.

Hogan, M. B.
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Horner, A. C.
History and Bibliography of Wood Diaphragm Tests—Summary of Proceedings of *STP 166*, 1245.

Houston, E. G.
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Howe, William A.
Survey of Diesel Fuel Oils Available at Roadside Filling Stations—Summary of Proceedings of *STP 167*, 1386.

Hoyt, W. B.
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Hunter, M. S., and Fricke, W. G., Jr.
Metallographic Aspects of Fatigue Behavior of Aluminum, 717. Disc., 735.

I

Ingle, George W.
A Color Space for Color Grading Purposes—Symposium on Color of Transparent and Translucent Products. Published in ASTM BULLETIN, No. 201, Oct., 36 (TP198). Disc., 40 (TP202); see also Summary of Proceedings, 1387.
Introduction to Symposium on Color of Transparent and Translucent Products. Published in ASTM BULLETIN, No. 201, Oct., 31 (TP193).

Irwin, G. R.
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Jackson, G. W., and Luce, W. A.
Screening Cast Stainless Steels by Electrolytic Etching in Oxalic Acid. Published in ASTM BULLETIN, No. 195, Jan., 71 (TP33).

Jessup, Ralph S., and Cogliano, Joseph A.
Relation Between Net Heat of Combustion and Aniline-Gravity Product of Aircraft Fuels. Published in ASTM BULLETIN, No. 201, Oct., 55 (TP217).

Johnson, A. I.
Selected References on Permeability—Summary of Proceedings of *STP 163*, 1244.

Jones, Chester W.
The Permeability and Settlement of Laboratory Specimens of Sand and Sand-Gravel Mixtures—Summary of Proceedings of *STP 163*, 1244.

Judd, Deane B.
Discussion. Published in ASTM BULLETIN, No. 201, Oct., 40 (TP202); No. 202, Dec., 71 (TP257).
Summary—Symposium on Color of Transparent and Translucent Products. Published in ASTM BULLETIN, No. 202, Dec., 72 (TP258); see also Summary of Proceedings, 1387.

Junge, Charles H.
Wear in Bearings—Symposium on Engine Lubrication. Published in ASTM BULLETIN, No. 198, May, 64 (TP110).

Juve, A. E., and Schoch, M. G., Jr.
The Effect of Temperature on the Air Aging of Rubber Vulcanizates. Published in ASTM BULLETIN, No. 195, Jan., 54 (TP16).

K

Keeney, Mark
Color in Dairy Products—Symposium on Color of Transparent and Translucent Products. Published in ASTM BULLETIN, No. 202, Dec., 70 (TP256); see also Summary of Proceedings, 1387.

Kesler, Clyde E.
Statistical Relation Between Cylinder, Modified Cube, and Beam Strength of Plain Concrete, 1178. Disc., 1187.

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Kiguchi, S. T.
See Myers, H. S., and Kiguchi, S. T.

Kirkham, Don
Measurement of the Hydraulic Conductivity of Soil in Place—Summary of Proceedings of *STP 163*, 1244.

Klute, C. H., and McKee, L. B.
Plastics Testing at High and Low Temperatures. Published in ASTM BULLETIN, No. 202, Dec., 50 (TP236).

Kobliska, J. J., and Rodenberger, H. J.
Mechanical Wet Sieve Testing Method. Published in ASTM BULLETIN, No. 200, Sept., 46 (TP172).

Krenchel, H.
Treatment of Tension Test Specimens for Fixing in Testing Machine. Published in ASTM BULLETIN, No. 200, Sept., 44 (TP170).

Kuhlmann, Harry W.
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L

Labbe, B. G.
A Study of Hardness Testing of Elastomers at Low Temperatures. Published in ASTM BULLETIN, No. 199, July, 73 (TP151).

Lakin, W. P.
See Moore, C. C., and Lakin, W. P.

Lambe, T. W.
The Permeability of Compacted Fine Grained Soils—Summary of Proceedings of *STP 163*, 1244.

Lampson, K.
See Green, A. W. F., Lampson, K., and Tsareff, T.

Larson, C. M.
The Availability and Demand Outlook, Distribution, and Principal Properties of Domestic Diesel Fuels—Summary of Proceedings of *STP 167*, 1386.

LaTour, Harry, and Sutton, R. S.
Improved Scale System for Stiffness Testing Machine. Published in ASTM BULLETIN, No. 196, Feb., 40 (TP48).

Lawrence, F. I. L.
Discussion. Published in ASTM BULLETIN, No. 198, May, 76 (TP122).

Lawrence, William N.
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Liska, J. A.
Summary to Symposium on Methods of Testing Building Constructions—Summary of Proceedings of *STP 166*, 1245.

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See Roesli, A., Loewer, A. C., and Eney, W. J.

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See Goldberg, D. C., and Lombardo, J. J.

Lortscher, L. L.
See Snyder, M. J., Lortscher, L. L., and Beatty, G. H.

Luce, W. A.
See Jackson, G. W., and Luce, W. A.

Lundgren, R.
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Luxford, R. F., and Heyer, Otto C.
Glued and Nailed Roof Trusses for House Construction—Summary of Proceedings of *STP 166*, 1245.

M

Mackay, William B. F.
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Creep-Time Relations for Nylon in Tension, Compression, Bending, and Torsion, 1313. Disc., 1342.

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Marshall, D. I.
Measuring Viscosity of Thermosetting Resins by Parallel Plate Plastometry. Published in ASTM |BULLETIN, No. 204, Feb., 1955, 40 (TP42).

Marshall, P. W.
See Heger, J. J., Hodge, J. M., and Marshall, P. W.

Mason, H. G., and Bishop, J. A.
Piles Subjected to Lateral Thrust: Part I—Measurement of Earth Pressure and Deflection Along the Embedded Portion of a 40-ft Steel Pile—*STP 154-A*, 1243.

Mather, Bryant
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Introduction to Symposium on Temperature Stability of Electrical Insulating Materials—Summary of Proceedings of *STP 161*, 1385.

Mavis, James O.
See Gould, Wilbur A., Davis, Rees B., and Mavis, James O.

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McBurney, J. W.
Masonry Cracking and Damage Caused by Moisture Expansion of Structural Clay Tile, 1219. Disc., 1241.

McCoy, W. J.
Water for Mixing and Curing Concrete—Summary of Proceedings of *STP 169*, 1242.

McGinnis, R. A.
Color Measurement and Control in the Sugar Industry—Symposium on Color of Transparent and Translucent Products. Published in ASTM BULLETIN, No. 201, Oct., 42 (TP204). See also Summary of Proceedings, 1387.

McKee, L. B.
See Klute, C. H., and McKee, L. B.

McKinley, Russell W.
See Deininger, Nicholas, and McKinley, Russell W.

McRae, J. L.
See Ricketts, W. C., Sprague, John C., Tabb, D. D., and McRae, J. L.

Meissner, H. S.
Significance of Tests and Properties of Mineral Admixtures—Summary of Proceedings of *STP 169*, 1242.

Messick, Harold V.
The Increasing Use of Furnace Oils for Diesel Fuel—Summary of Proceedings of *STP 167*, 1386.

Middleton, W. E. K.
Discussion. Published in ASTM BULLETIN, No. 201, Oct., 40, 48 (TP210).

Mielenz, Richard C.
Petrographic Examination of Concrete Aggregate, 1188; see also Summary of Proceedings of *STP 169*, 1242.

Miller, James
Effect of Temperature Cycling on the Rupture Strength of Some High-Temperature Alloys—Summary of Proceedings of *STP 165*, 700.

Miller, R. F.
The Strength of Carbon Steels for Elevated-Temperature Applications, 964. Disc., 993.

Minnick, L. John
Investigations Relating to the Use of Fly Ash as a Pozzolanic Material and as an Admixture in Portland-Cement Concrete, 1129. Disc., 1163.

Miskimen, T. A., and Thurston, R. S.
Multilot Sampling—The Accuracies in Sampling of Large Coal Shipments by Application of the Variance Concept—Summary of Proceedings of *STP 162*, 1384.

Modine, N., and O'Connor, D. T.
Radiographic-Micrographic Examination of Aluminum Resistance Weld. Published in special reprint only.

Monk, C. B., Jr.
Transverse Strength of Masonry Walls—Summary of Proceedings of *STP 166*, 1245.

Moore, C. C., and Lakin, W. P.
Distribution and Storage Problems with Diesel Fuels—Summary of Proceedings of *STP 167*, 1386.

Morgan, H. I., and Mathes, K. N.
The Deflected Beam-Film Rupture Test Applied to Sheet Insulation—Summary of Proceedings of *STP 161*, 1385.
Heat Aging Characteristics of Insulating Varnishes—Summary of Proceedings of *STP 161*, 1385.

Mougey, H. C.
Engine Wear as Affected by Lubricant Composition—Symposium on Engine Lubrication. Published in ASTM BULLETIN, No. 198, May, 57 (TP103).

Mudge, W. L., Jr.
See Manjoine, M. J., and Mudge, W. L., Jr.

Muhlenbruch, Carl W.
A Tension Impact Test for Sheet Metals. Published in ASTM BULLETIN, No. 196, Feb., 43 (TP51). Disc., 49 (TP57).

Myers, H. S., and Kiguchi, S. T.
An Apparatus for Making ASTM-Type Vacuum Distillations. Published in ASTM BULLETIN, No. 195, Jan., 39 (TP1).

Myers, W. R.
Analysis for Molybdenum-Bearing Austenitic Stainless Steel Proposed for Experimental Use in Chemical and Process Industries. Published in ASTM BULLETIN, No. 201, Oct., 28.

N

Nelson, K. E.
Tensile and Creep Properties at Elevated Temperatures of Some Magnesium-Base Sand-Casting Alloys, 1081.

Newhall, Sidney
Discussion. Published in ASTM BULLETIN, No. 201, Oct., 40 (TP202); No. 202, Dec., 69 (TP255).

Newhouse, D. L.
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Newman, Sanford B., Hammond, Harry K., III, and Riddell, Helen F.
Becker Value of Manila Rope by Photoelectric Reflectometry. Published in ASTM BULLETIN, No. 199, July, 84 (TP162).

Nickerson, Dorothy
Discussion. Published in ASTM BULLETIN, No. 202, Dec., 71 (TP257).

Norén, Bengt
Relation Between Compressive Strength and Rate of Deformation in Testing Swedish Fir. Published in ASTM BULLETIN, No. 202, Dec., 43 (TP229).

Norris, H. B.
The Correlation of the Betatron with Other Forms of Non-Destructive Testing. Published in ASTM BULLETIN, No. 197, Apr., 56 (TP84).

O

O'Connor, D. T.
See Criscuolo, E. L., and O'Connor, D. T.
See Modine, N., and O'Connor, D. T.
See Polansky, D., and O'Connor, D. T.

O'Connor, D. T., and Criscuolo, E. L.
Radiographic-Performance Correlation in Ordnance Design and Evaluation. Published in special reprint only.

Oliensis, G. L.
Discussion. Published in ASTM BULLETIN, No. 199, July, 60 (TP138).

P

Painter, R. J.
What Standards Mean to Us—General Comments and Background. Published in ASTM BULLETIN, No. 203, Jan., 1955, 41 (TP1).

Paitchel, H.
See Diaz, R. B., Paitchel, H., and Woodhead, J. A.

Palchoudhuri, A.
See Polakowski, N. H., and Palchoudhuri, A.

Palmer, L. A., and Brown, P. P.
Piles Subjected to Lateral Thrust: Part II—Analysis of Pressure Deflection, Moment, and Shear by the Method of Difference Equations—*STP 154-A*, 1243.

Parente, E. J.
See Coryell, R. L., Schwerd, F. J., and Parente, E. J.

Parker, Frank C.
Discussion. Published in ASTM BULLETIN, No. 196, Feb., 60 (TP68).

Peck, Charles F., Jr.
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Peterson, R. E.
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Plettner, R. M., and Currin, C. G.
A Method for Evaluation of the Thermal Aging Stability of Flexible Sheet Insulation —Summary of Proceedings of *STP 161*, 1385.

Polakowski, N. H., and Palchoudhuri, A.
Softening of Certain Cold-Worked Metals Under the Action of Fatigue Loads, 701. Disc., 715.

Polansky, D., and O'Connor, D. T.
The Reliability of Fluoroscopic Inspection of Extruded Propellant. Published in special reprint only.

Port, J. H., and Blank, A. I.
The Creep Characteristics of Copper-Nickel Alloys at 300, 400, and 500 F, 1038.

Power, William R.
The Invalid Induction Period. Published in ASTM BULLETIN, No. 200, Sept., 58 (TP184).

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Raring, R., and Rinebolt, J.
Notch-Bar Tests of High-Strength Steel, 956. Disc., 963.

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Size Effect in the Tension Test of Mild Steel, 995. Disc., 1002.

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An Evaluation of the Specific Gravity of Aggregates for Use in Bituminous Mixtures, 1246. Disc., 1257.

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See Kobliska, J. J., and Rodenberger, H. J.

Roesli, A., Loewer, A. C., and Eney, W. J.
Machine to Apply Repeated Loads to Large Flexural Members. Published in ASTM BULLETIN, No. 196, Feb., 50 (TP58).

Rogers, P. L.
Developing a Test Method for Efflorescence of Masonry Mortar. Published in ASTM BULLETIN, No. 200, Sept., 64 (TP190).

Romualdi, J. P., and D'Appolonia, E.
Effect of Range of Stress and Prestrain on the Fatigue Properties of Titanium, 798. Disc., 820.

Romualdi, James P., Chang, Chiao-Lin, and Peck, Charles F., Jr.
A Fatigue Testing Machine for Range of Stress. Published in ASTM BULLETIN, No. 200, Sept., 39 (TP165).

Rowe, Robert S.
Autogenesis. Published in ASTM BULLETIN, No. 201, Oct., 63 (TP225).

Ruff, R. J.
Catalytic Method of Measuring Hydrocarbon Concentrations in Industrial Exhaust Fumes—Summary of Proceedings of *STP 164*, 1383.

Rush, A. I., and Freeman, J. W.
Statistical Evaluation of the Creep-Rupture Properties of Four Heat-Resistant Alloys in Sheet Form, 1098. Disc., 1125.

S

Sagarin, Edward
Odor: A Proposal for Some Basic Definitions —Summary of Proceedings of *STP 164*, 1383.

Savage, W. T.
Introduction to Symposium on Methods of Testing Building Constructions—Summary of Proceedings of *STP 166*, 1245.

Schaefer, A. O.
A Producer Looks at Standards. Published in ASTM BULLETIN, No. 203, Jan., 1955, 45 (TP5).

Schoch, M. G., Jr.
See Juve, A. E., and Schoch, M. G., Jr.

Scholer, C. H.
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A Simplified Statistical Procedure for Obtaining Design-Level Fatigue Curves, 853. Disc., 872.

Schwartzbart, Harry, and Sheehan, J. P.
Effect of Specimen Size on Notched Bar Impact Properties of Quenched-and-Tempered Steels, 939. Disc., 954.

Schweizer, E.
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See Coryell, R. L., Schwerd, F. J., and Parente, E. J.

Scofield, Francis
Color of Transparent Liquids for Surface Coatings—Symposium on Color of Transparent and Translucent Products. Published in ASTM BULLETIN, No. 202, Dec., 68 (TP254). Disc., 69 (TP255); see also Summary of Proceedings, 1387.

Scott, A. H., Ehrlich, Paul, and Richardson, J. F.
Measurement of Dielectric Properties at Temperatures up to 500 C—Summary of Proceedings of *STP 161*, 1385.

Scripture, E. W., Jr.
Setting Time of Concrete—Summary of Proceedings of *STP 169*, 1242.

Seed, H. B., and Lundgren, R.
Investigation of the Effect of Transient Loading on the Strength and Deformation Characteristics of Saturated Sands, 1288.

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Seniff, R. W.
Technical Problems Associated with Diesel Fuels in Railroad Operations—Summary of Proceedings of *STP 167*, 1386.

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- High Temperature
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- Highway Materials
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- Honorary Membership Awards
  - Summary of Proceedings of the Fifty-seventh Annual Meeting, 9.
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      - proposed method. Report of Comm. D-16, 510.
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- Insulating Materials
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    - Symposium on Temperature Stability of Electrical Insulating Materials. Summary of Proceedings of *STP 161*, 1385:
      - deflected beam-film rupture test (Morgan and Mathes).
      - dielectric
        - properties (Scott, Ehrlich, and Richardson).
        - measurements on plastics (Hazen).

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electrical resistivity (Wechsler).
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flexible sheet insulation (Plettner and Currin).
heat aging characteristics (Morgan and Mathes).
insulating varnishes (Haroldson).
polyvinyl chloride compounds (Bartlett).
silicone varnished glass fabric (Anderson).
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Low Temperature
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plastics testing (Klute and McKee). Published in ASTM BULLETIN, No. 202, Dec., 50 (TP236).
stiffness testing elastomers (Conant). Published in ASTM BULLETIN, No. 199, July, 67 (TP145).
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Papers on Non-Destructive Testing. Published in ASTM BULLETIN, No. 196, Feb., No. 197, Apr., and No. 198, May; also available in special reprint:
betatron (Norris), Apr., 56 (TP84).

    flash X-ray studies (Criscuolo and O'Connor). Published in special reprint only.
    fluoroscopic inspection (Polansky and O'Connor). Published in special reprint only.
    gamma radiography and Magnaflux indications (Thompson), Apr., 58 (TP86).
    radiographic-performance in ordnance (O'Connor and Criscuolo). Published in special reprint only.
    radiographic-micrographic examination (Modine and O'Connor). Published in special reprint only.
    ultrasonic frequencies (Cook and VanValkenburg), May, 81 (TP127).
    ultrasonic reflectoscope (Tarr), Feb., 54 (TP62).
    ultrasonic testing of forging ingots (Hafemeister), Apr., 52 (TP80).
  steel connecting rods
    gamma ray and magnaflux (Thompson). Published in ASTM BULLETIN, No. 197, Apr., 58 (TP86).
  ultrasonic frequency (Cook and VanValkenburg). Published in ASTM BULLETIN, No. 198, May, 81 (TP127).
  X-ray in 2- and 6-million volts (Goldie, Wright, Anson, Cloud, and Trump). Published in ASTM BULLETIN, No. 201, Oct., 49 (TP211).
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    pollution, official's viewpoint (Gruber).
    test room design, construction, and use (Deininger and McKinley).
    three-component mixtures, organoleptic appraisal (Gee).
Oil
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  motor
    viscosity (Foreman), Disc. Published in ASTM BULLETIN, No. 200, Sept., 55 (TP181).
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  chip resistance measurement (Brightwell). Published in ASTM BULLETIN, No. 200, Sept., 53 (TP179).
  hiding power test (Switzer). Published in ASTM BULLETIN, No. 197, Apr., 60 (TP88).
  Report of Comm. D-1, 396.
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    proposed specifications. Published in Jan., 1955, Compilation of ASTM Standards on Paint, Varnish, Lacquer, and Related Products.
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  jet fuels
    filterability
      proposed method of test. Published in Nov., 1954, Compilation of ASTM Standards on Petroleum Products and Lubricants.
    mercaptan sulfur
      proposed method of test. Published in Nov., 1954, Compilation of ASTM Standards on Petroleum Products and Lubricants.
  steam-turbine oils
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      proposed method of test. Published in Nov., 1954, Compilation of ASTM Standards on Petroleum Products and Lubricants.
  reduced pressure distillation
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  temperature measurement
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Petroleum Products
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    proposed specifications. Report of Comm. E-1, 554.
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  impact machine (Burns). Published in ASTM BULLETIN, No. 195, Jan., 61 (TP23).
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    susceptibility to attack by rats. Published in Sept., 1954, Compilation of ASTM Standards on Adhesives.
    susceptibility to attack by roaches. Published in Sept., 1954, Compilation of ASTM Standards on Adhesives.
  aromatic hydrocarbons
    bromine index. Report of Comm. D-16, 510.
  aviation fuels
    dielectric constant. Published in Feb., 1955, Compilation of ASTM Standards on Electrical Insulating Materials.
  cement mortar
    compressive strength
      mechanical mixing. Published in ASTM BULLETIN, No. 196, Feb., 24.
  cotton
    dyeing behavior. Published in Oct., 1954, Compilation of ASTM Standards on Textile Materials.
  paint
    safflower oil. Published in Jan., 1955, Compilation of ASTM Standards on Paint, Varnish, Lacquer, and Related Products.
  petroleum
    determination of water by distillation. Report of Comm. E-1, 554.
    hydrocarbons in C_4 fraction
      infrared spectrophotometry. Published in Nov., 1954, Compilation of ASTM Standards on Petroleum Products and Lubricants.
    jet fuels
      filterability. Published in Nov., 1954, Compilation of ASTM Standards on Petroleum Products and Lubricants.
      mercaptan sulfur. Published in Nov., 1954, Compilation of ASTM Standards on Petroleum Products and Lubricants.
    steam-turbine oils
      emulsion characteristics. Published in Nov., 1954, Compilation of ASTM Standards on Petroleum Products and Lubricants.
  water
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    industrial wastes
      toxicity to fishes. Published in 1954 Supplement to Book of ASTM Standards, Part 7, and in Sept., 1954, printing of Manual on Industrial Water.
  wax polishes
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    dynamic coefficient of friction. Published in ASTM BULLETIN, No. 196, Feb., 21.
    index of refraction. Published in ASTM BULLETIN, No. 197, Apr., 39.
    static coefficient of friction. Published in ASTM BULLETIN, No. 196, Feb., 20.
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  X-rays in 2- and 6-million volts (Goldie, Wright, Anson, Cloud, and Trump). Published in ASTM BULLETIN, No. 201, Oct., 49 (TP211).
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  Report of Comm. D-11, 481.
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      petrographic examination of aggregate (Mielenz). (Also included in these *1954 Proceedings*, 1188. (*R*))
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Strain Gage
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  - test specimens
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- Test Sites
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  - constant-load (Clark and Sidebottom). Published in ASTM BULLETIN, No. 203, Jan., 1955, 69 (TP29).
  - fatigue
    - range of stress (Romualdi, Chang, and Peck). Published in ASTM BULLETIN, No. 200, Sept., p. 39 (TP165).
  - flexural
    - repeated loads (Roesli, Loewer, and Eney). Published in ASTM BULLETIN, No. 196, Feb., 50 (TP58).
  - four piece steamer (Antelman). Published in ASTM BULLETIN, No. 197, Apr., 66 (TP94).
  - impact for textiles (Dickson and Davieau). Published in ASTM BULLETIN, No. 198, May, 85 (TP131).
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  - stiffness
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  - triaxial stress
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  - vacuum distillations (Myers and Kiguchi). Published in ASTM BULLETIN, No. 195, Jan., 39 (TP1).
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- Textiles
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  - impact tester (Dickson and Davieau). Published in ASTM BULLETIN, No. 198, May, 85 (TP131).
  - Report of Comm. D-13, 493, 496.
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- Thermal Shock
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    - durability of asphalt coatings. Disc. Published in ASTM BULLETIN, No. 199, July 60 (TP138).
- Thermometers
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- Ultrasonic Testing
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    abbreviated methods for analysis. Published in Sept., 1954, printing of Manual on Industrial Water.
  industrial
    Report of Comm. D-19, 520.
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  industrial wastes
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      proposed method of test. Published in 1954 Supplement to Book of ASTM Standards, Part 7, and in Sept., 1954, printing of Manual on Industrial Water.
Waterproofing
  Report of Comm. D-8, 440.
Wax
  Report of Comm. D-21, 538.
Wax Polishes
  additives
    proposed methods. Published in ASTM BULLETIN, No. 197, Apr., 38.
  dynamic coefficient of friction
    proposed methods. Published in ASTM BULLETIN, No. 196, Feb., 21.
  index of refraction
    proposed methods. Published in ASTM BULLETIN, No. 197, Apr., 39.
  static coefficient of friction
    proposed methods. Published in ASTM BULLETIN, No. 196, Feb., 20.
Wear
  bearings (Junge). Published in ASTM BULLETIN, No. 198, May, 64 (TP110).
  engine
    lubricant effect (Mougey). Published in ASTM BULLETIN, No. 198, May, 57 (TP103).
Weathering
  plastics (Yustein, Winans, and Stark). Published in ASTM BULLETIN, No. 196, Feb., 29 (TP37). Disc., 38 (TP46).
  Report of Comm. B-3, 147.
Welding Rods
  stainless steel specifications. Published in ASTM BULLETIN, No. 98, May, 77 (TP123).
Welds
  ultrasonic reflectoscope inspection (Tarr). Published in ASTM BULLETIN, No. 196, Feb., 54 (TP62). Disc., 60 (TP68).
Whiteware
  ceramic
    Report of Comm. C-21, 392.
Wire
  Report of Comm. A-5, 123.
  Report of Comm. B-1, 138.
Wood
  Report of Comm. D-7, 437.
  Swedish fir
    compressive strength and rate of shear (Norén). Published in ASTM BULLETIN, No. 202, Dec., 43 (TP229).
Wool
  Report of Comm. D-13, 493.

X

X-Ray Testing
  correlation of Betatron (Norris). Published in ASTM BULLETIN, No. 197, Apr., 56 (TP84).

Z

Zirconium
  creep properties (Manjoine and Mudge), 1050